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# Thoms, Salmon Bay, and Luck Lakes Subsistence Sockeye Salmon Project: 2003 Annual Report and 2001-2003 Final Report

**by**

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**Alaska Department of Fish and Game** **Divisions of Sport Fish and Commercial Fisheries**

# Symbols and Abbreviations

The following symbols and abbreviations, and others approved for the Système International d'Unités (SI), are used without definition in the following reports by the Divisions of Sport Fish and of Commercial Fisheries: Fishery Manuscripts, Fishery Data Series Reports, Fishery Management Reports, and Special Publications. All others, including deviations from definitions listed below, are noted in the text at first mention, as well as in the titles or footnotes of tables, and in figure or figure captions.

**Weights and measures (metric)**

| | |
|---|---|
| centimeter | cm |
| deciliter | dL |
| gram | g |
| hectare | ha |
| kilogram | kg |
| kilometer | km |
| liter | L |
| meter | m |
| milliliter | mL |
| millimeter | mm |

**Weights and measures (English)**

| | |
|---|---|
| cubic feet per second | $ft^3/s$ |
| foot | ft |
| gallon | gal |
| inch | in |
| mile | mi |
| nautical mile | nmi |
| ounce | oz |
| pound | lb |
| quart | qt |
| yard | yd |

**Time and temperature**

| | |
|---|---|
| day | d |
| degrees Celsius | °C |
| degrees Fahrenheit | °F |
| degrees kelvin | K |
| hour | h |
| minute | min |
| second | s |

**Physics and chemistry**

| | |
|---|---|
| all atomic symbols | |
| alternating current | AC |
| ampere | A |
| calorie | cal |
| direct current | DC |
| hertz | Hz |
| horsepower | hp |
| hydrogen ion activity (negative log of) | pH |
| parts per million | ppm |
| parts per thousand | ppt, ‰ |
| volts | V |
| watts | W |

**General**

| | |
|---|---|
| Alaska Administrative Code | AAC |
| all commonly accepted abbreviations | e.g., Mr., Mrs., AM, PM, etc. |
| all commonly accepted professional titles | e.g., Dr., Ph.D., R.N., etc. |
| at | @ |
| compass directions: | |
| east | E |
| north | N |
| south | S |
| west | W |
| copyright | © |
| corporate suffixes: | |
| Company | Co. |
| Corporation | Corp. |
| Incorporated | Inc. |
| Limited | Ltd. |
| District of Columbia | D.C. |
| et alii (and others) | et al. |
| et cetera (and so forth) | etc. |
| exempli gratia (for example) | e.g. |
| Federal Information Code | FIC |
| id est (that is) | i.e. |
| latitude or longitude | lat. or long. |
| monetary symbols (U.S.) | $, ¢ |
| months (tables and figures): first three letters | Jan,...,Dec |
| registered trademark | ® |
| trademark | ™ |
| United States (adjective) | U.S. |
| United States of America (noun) | USA |
| U.S.C. | United States Code |
| U.S. state | use two-letter abbreviations (e.g., AK, WA) |

**Measures (fisheries)**

| | |
|---|---|
| fork length | FL |
| mideye-to-fork | MEF |
| mideye-to-tail-fork | METF |
| standard length | SL |
| total length | TL |

**Mathematics, statistics**

| | |
|---|---|
| *all standard mathematical signs, symbols and abbreviations* | |
| alternate hypothesis | $H_A$ |
| base of natural logarithm | *e* |
| catch per unit effort | CPUE |
| coefficient of variation | CV |
| common test statistics | (F, t, $\chi^2$, etc.) |
| confidence interval | CI |
| correlation coefficient (multiple) | R |
| correlation coefficient (simple) | r |
| covariance | cov |
| degree (angular ) | ° |
| degrees of freedom | df |
| expected value | *E* |
| greater than | > |
| greater than or equal to | ≥ |
| harvest per unit effort | HPUE |
| less than | < |
| less than or equal to | ≤ |
| logarithm (natural) | ln |
| logarithm (base 10) | log |
| logarithm (specify base) | $log_{2,}$ etc. |
| minute (angular) | ' |
| not significant | NS |
| null hypothesis | $H_O$ |
| percent | % |
| probability | P |
| probability of a type I error (rejection of the null hypothesis when true) | α |
| probability of a type II error (acceptance of the null hypothesis when false) | β |
| second (angular) | " |
| standard deviation | SD |
| standard error | SE |
| variance | |
| population | Var |
| sample | var |

*FISHERY DATA SERIES NO. 06-08*

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# ABSTRACT

In 2001, 2002, and 2003, we examined Thoms, Salmon Bay, and Luck lakes—sockeye producing systems near the community of Wrangell, Alaska—to assess the status of these stocks relative to the size of the subsistence harvests and to develop baseline information on freshwater habitat. In 2003 we were unable to measure escapements into Thoms and Salmon Bay lakes because of weather and other problems. Nevertheless, during the study years, escapements were judged to be high, relative to our subsistence harvest measures. In Thoms Lake, the sockeye escapement estimate approximately doubled each year: 3,000 fish in 2001, 5,900 fish in 2002 and 11,200 fish in 2003. Similar to Thoms Lake, the estimated 2001 sockeye escapement in Salmon Bay Lake (20,000 fish) and Luck Lake (8,000 fish) almost doubled in 2002 (43,000 fish and 16,000 fish, respectively). Subsistence harvest was assessed by means of returned permits. Even allowing for a substantial undercount in the reported harvest, the subsistence harvests in these years did not seem large enough to appreciably affect future recruitment. With only three years of observation, any inference from the limnological measurements is only speculative. Even so, because we did not see zooplankton populations decline with increasing sockeye fry measures in all three lakes, we assume that the escapements during these years were below levels that produce maximum fry recruitment. We see no reason to think subsistence harvests pose much risk to sustainability in these systems in the near future.



Key Words: sockeye salmon, *Oncorhynchus nerka*, Thoms Lake, Salmon Bay Lake, Luck Lake, Prince of Wales Island, Wrangell Island, stock assessment, limnology, zooplankton, harvest, subsistence, escapement, fry, hydroacoustic


# INTRODUCTION

Aboriginal Tlingits used Thoms, Salmon Bay, and Luck lakes well before recorded history (Goldschmidt and Haas 1998). Thoms Lake was in territory claimed by the Kiks.ádi clan, and Luck and Salmon Bay Lakes were primarily within territory claimed by the Teeyhittaan clan; all three areas had cabins and smokehouses used by fishing and hunting parties at least through the early 1900s. In more recent times, Wrangell residents documented their subsistence harvest of sockeye salmon from Thoms and Salmon Bay lakes on the Alaska Department of Fish and Game (ADF&G) subsistence permits (Appendix A1). Luck Lake had very little history of subsistence fishing—the only reported harvest was 22 sockeye salmon in 1990—but the residents on Prince of Wales Island are interested in developing subsistence opportunities in this system. The areas adjacent to these lakes are closed to commercial harvest to ensure an adequate return of salmon for subsistence opportunities and escapement. Still, we have no means to determine the number of sockeye salmon from a given system that are taken in the mixed-stock commercial fisheries.

These three lakes have sporadic escapement observations from foot and aerial surveys, and a weir was operated on Salmon Bay Lake during the mid-1960s and 1980s (Lewis and Cartwright 2004). Measured escapements into Salmon Bay Lake ranged from 3,700 to 11,600 fish between 1965 and 1968 and 9,000 to 34,000 fish between 1982 and 1988. The outlet of Luck Lake had a weir in the 1930s (Lewis and Cartwright 2004), which measured escapement levels from 2,000 to 15,700 fish. Residents of Prince of Wales Island were interested in a subsistence fishery in Eagle Creek, at the outlet of Luck Lake. ADF&G managers have been interested in adding Eagle Creek to their subsistence permit, but they lacked stock assessment information and evidence that the run into Luck Lake was large enough to allow a fishery.

Our goal with this three-year study was to gather information about these sockeye salmon populations and their habitat, and our main purpose was to estimate the approximate escapement levels in each system. Because our study was limited to freshwater phases of sockeye life history, we examined sockeye production only in terms of escapement, and juvenile populations and their rearing habitat. We conducted mark-recapture studies on the major spawning aggregations, once the salmon had moved on to the spawning grounds. We also estimated sockeye fry and zooplankton populations in each lake and collected some information on the physical habitat. Although other studies have shown that subsistence fishers underestimate their reported catch on the ADF&G subsistence permits (Lewis and Cartwright 2004; Conitz and Cartwright 2005), we used these returned harvest permits to develop our measures of subsistence harvest in each system. These statistics generated from the returned permits are probably reliable for tracking trends across years, and we have found them acceptable for roughly gauging the level of subsistence take. In addition to our statistical information, we included a section on field notes, in Appendix A2. This section contains recommended changes in study design and provides other observations, should this study be continued again in the future.

# OBJECTIVES

1. Estimate escapement of sockeye salmon into each lake using mark-recapture methods so that the estimated coefficient of variation is less than 15%.
2. Describe the age and size distribution of the sockeye spawning population by sex and lake.
3. Estimate number of sockeye fry in Luck Lake using hydroacoustic and trawl surveys methods so that the estimated sockeye fry population has a coefficient of variation less than 15%.
4. Collect baseline data on productivity of each lake using established ADF&G limnological sampling procedures.

# METHODS

## STUDY SITES

Thoms Lake, approximately 20 km south of Wrangell, is located on the southwest side of Wrangell Island in lower Zimovia Strait (lat 56°11.02'N, long 132°08.30'W; ADF&G stream number 107-30-30; Figure 1). This dimictic lake is approximately 2.7-km long, has a surface area of 153 hectares, an elevation of 85 meters, and a maximum depth of 33 meters (Figure 2). The lake water is clear with some seasonal organic staining. Thoms Lake empties into Thoms Place on Zimovia Strait via Thoms Creek (9.6 km). A logging road crosses Thoms Creek near its outlet, accessing several small clearcuts in the lower watershed. Native fish species include cutthroat trout (*Oncorhynchus clarkii clarkii*), Dolly Varden (*Salvelinus malma*), three spine stickleback (*Gasterosteus aculeatus*), cottids (*Cottus* sp.), steelhead (*O. mykiss*), and pink (*O. gorbusha*), chum (*O. keta*), coho (*O. kisutch*), and sockeye (*O. nerka*) salmon. There are two main tributaries, East and Little East Creeks, on the north end of the lake with several small inflows scattered along the shore and the outlet stream leaves the lake at its southern most tip (Figure 2). East Creek is the primary sockeye and coho salmon spawning area. Limnological sampling occurred at sites A (lat 56º14.54’N, long 14º14.49’W) and B (lat 56º14.23’N, long 14º14.74’W).

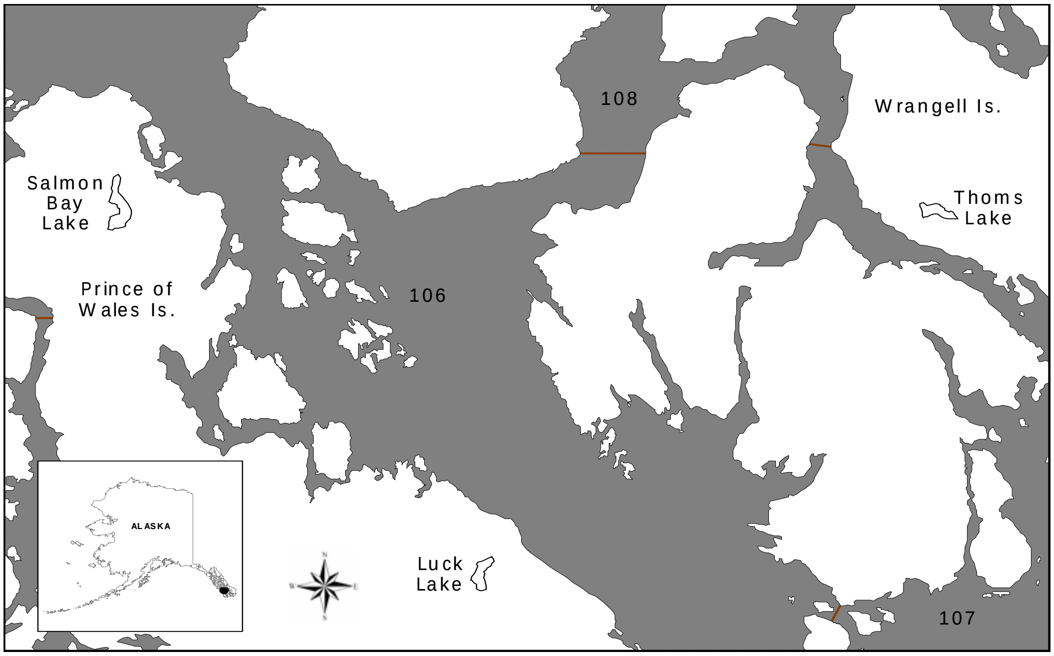


**Figure 1.–**The geographic location of Thoms, Luck, and Salmon Bay lakes within Southeast Alaska (see insert). The numbers in the marine waters represent commercial fishing districts adjacent to these three lakes.

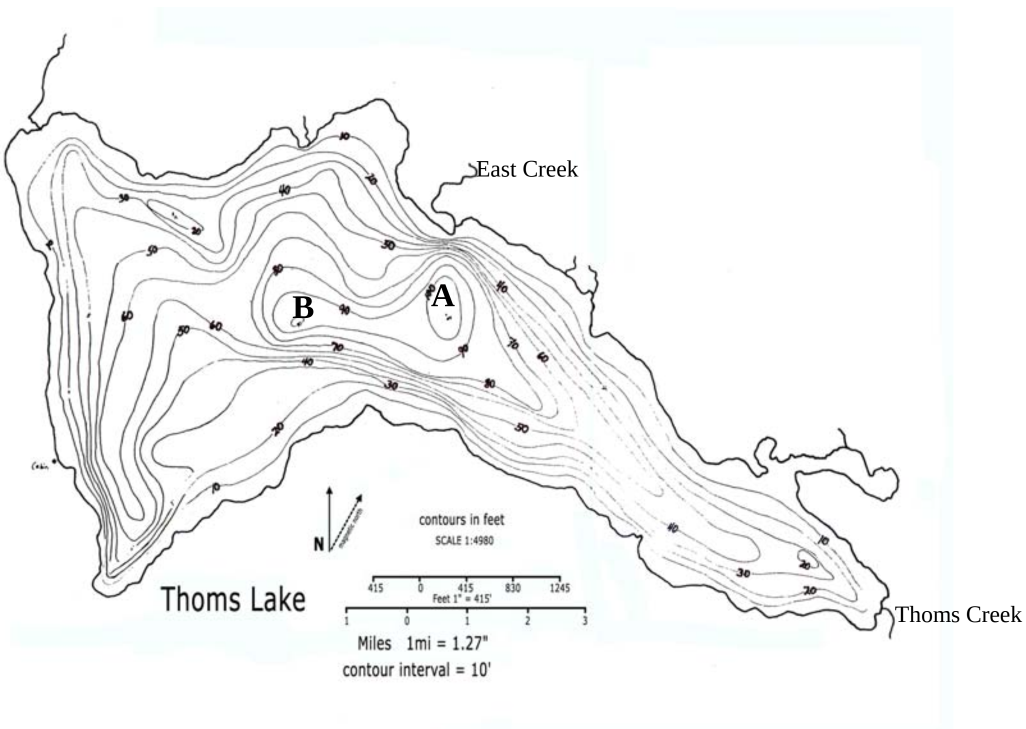


**Figure 2**.–Bathymetric map of Thoms Lake on Wrangell Island in Southeast Alaska with limnological sampling locations (A and B). Depth contours are shown in 10 ft. intervals.

Salmon Bay Lake, approximately 30 km west of Wrangell, is located on the northeast side of the Prince of Wales Island (lat 56°15.88'N, long 133°10.55.0'W; ADF&G stream number 106-41-010; Figure 1). This dimictic lake is approximately 4.8-km long, has a surface area of 400 hectares, an elevation of 15 meters, a mean depth of 26.7 meters, and a maximum depth of 60 meters (Figure 3). The volume of this lake is estimated to be 103.9 million cubic meters. Salmon Bay Lake empties into the west side of Clarence Strait via Salmon Bay Creek (2 km) and Salmon Bay. Native fish species include cutthroat trout, Dolly Varden, stickleback, cottids, steelhead, and pink, chum, coho, and sockeye salmon. Three unnamed tributaries on the south end of the lake are referred to as the southwest head, south head, and east head streams. These streams represent the primary sockeye and coho salmon spawning areas. Logging and roads from adjacent drainages extend into the Salmon Bay drainage, but there are no roads or clearcuts immediately adjacent to or crossing the lake, major tributaries, or the outlet stream.

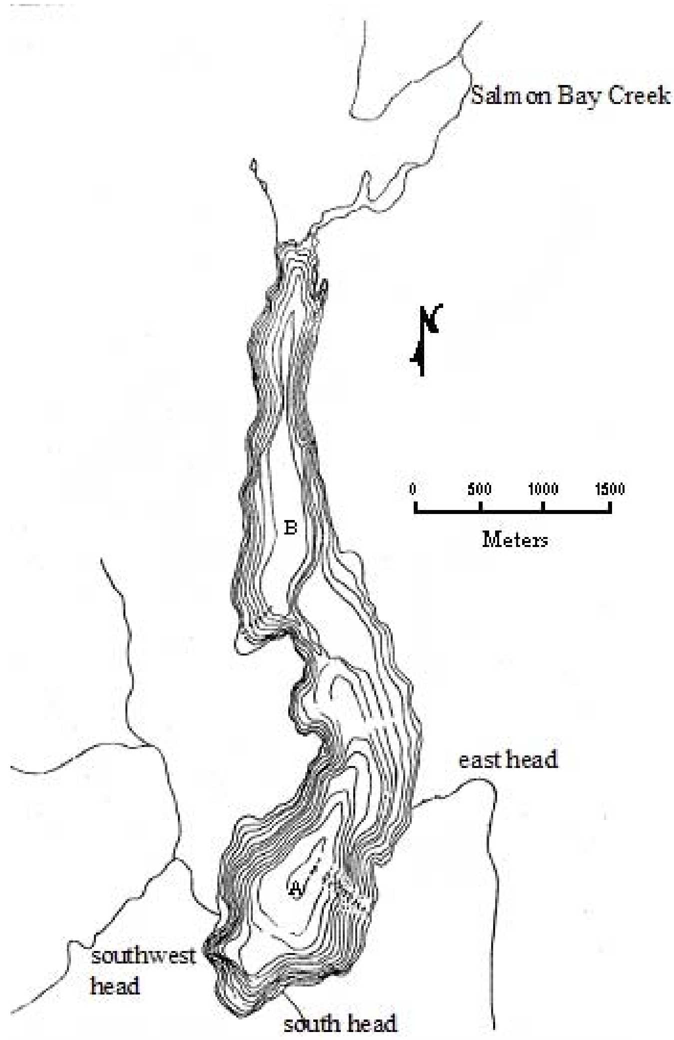


**Figure 3.–**Bathymetric map of Salmon Bay Lake on Prince of Wales Island in Southeast Alaska with limnological sampling locations (A and B). Depth contours are shown in intervals of 5 meters.

Luck Lake, approximately 20 km north of Thorne Bay, is located on the northeast side of Prince of Wales Island (lat 55°58.0'N, long 132°46.0'W; ADF&G stream number 106-10-034; Figure 1). This dimictic lake has a maximum depth of 38 m, an area of 210 hectares, is 3.2-km long and 0.8 km wide, and a total drainage area of about 77 $km^2$ (Figure 4). The outlet stream, Eagle Creek, is located at the north end of the lake, is about 2.8-km long and empties into salt water about 2.9-km south of Luck Point in a steep, rocky inter-tidal zone. Luck Creek is the major inlet stream and is located on the south end of the lake. This 12-km long stream is the primary spawning area for sockeye and coho salmon and has several large tributaries. Cascading falls at about 1.9 and 1.6-km upstream impede migration, but some sockeye salmon do spawn above the falls. The lower part of the east fork tributary is also heavily used by spawning sockeye salmon, coho salmon, and Dolly Varden. An old landslide on the tributary created a 2.4 m barrier falls at about 1.2 km from the confluence with the mainstem stream. The Luck Lake drainage has been extensively logged and roads cross the main inlet and the outlet stream. Limnological sampling occurred at sites A (lat 55º56.90’N, long 132º46.45W) and B (lat 55º56.20N, long 132º46.53W).

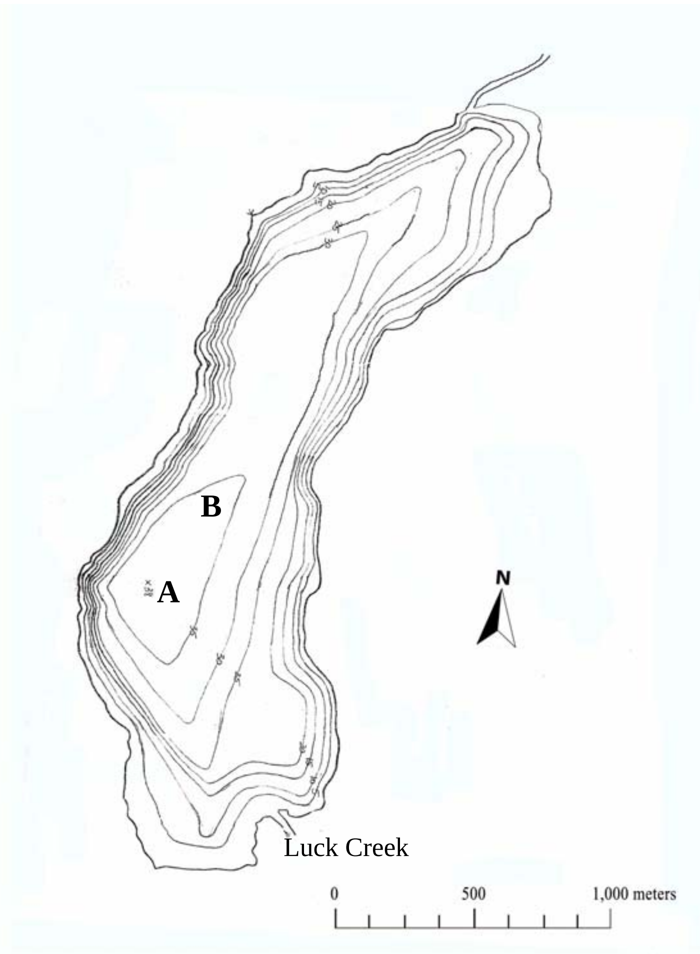


**Figure 4.–**Bathymetric map of Luck Lake on Prince of Wales Island in Southeast Alaska with limnological sampling stations (A and B). Depth contours are shown in intervals of 5 meters.

## SOCKEYE ESCAPEMENT ESTIMATES

We used mark-recapture methods to estimate the sockeye escapement in the major spawning stream(s) in each lake. Because the capture probability may have varied over time, a stratified mark-recapture procedure was used to estimate escapement (Seber 1982; Arnason et al. 1996). In a temporally stratified mark-recapture experiment, individuals released during each series of non-overlapping periods (strata) bear a release-period specific mark, so that each recaptured fish can be identified by the period during which it was released and period during which it was recaptured. To justify the estimate we need to be able to make the following assumptions:

1) Closure, no fish enter or leave between the two sample times;
2) No mark loss, fish retain their marks and are correctly identified as marked or unmarked;
3) Equal catchability, all fish in a given recapture stratum, whether marked or unmarked, have the same probability of being sampled.

Additionally, we assumed that there was no spawning outside of the study areas.

The field crew conducted 4 to 6 mark-recapture sampling trips in each system, approximately every two weeks over the entire spawning period. Prior to each mark-recapture event, visual counts of sockeye spawners were made by each crewmember in the inlet stream(s). Each inlet stream was defined as a separate sampling domain.

The crew sampled and marked sockeye salmon staging at the mouth of the inlet stream(s) (first samples). At the mouth of inlet streams the fish were sampled with beach seines. These seines were 20 m long and 4 m deep, and pulled by a small skiff with outboard motor to surround the sockeye salmon staging at the mouth of the stream. All sockeye salmon caught were first inspected for previous marks, then marked with an opercle punch or pattern of punches indicating the trip and the day within the trip, and released with a minimum of stress. The total number of new fish marked at the mouth of the stream was recorded by set and day. Each marking stratum was identified with a distinct opercular punch shape: stratum 1–round, stratum 2–triangle, stratum 3–square, and stratum 4–2 round holes. The primary mark was put in the left operculum to distinguish fish from this stream area from those marked in the beach spawning area.

When sockeye salmon were observed spawning within the inlet stream(s), the crew sampled fish in the stream (recapture samples) using a small barrier net or dipnets. Global Positioning System (GPS) waypoints marked the boundaries of each study area. All parts of the stream were sampled as evenly as possible. In this second sample stage, or recapture phase, live fish caught upstream were examined for marks; carcasses were also examined for marks. We recorded both the number of marked and unmarked fish from each stratum. A secondary mark was given all live fish and carcasses in the second samples to prevent re-counting. Sample sizes were as large as practical while avoiding multiple same-day recaptures. The first trip coincided with the time that sockeye salmon were beginning to stage off the stream mouth but before they entered the stream. Only the marking phase was conducted on the first trip. On subsequent trips, spaced about two weeks apart, both the marking and recapture phases were conducted, until there were no more sockeye spawners at the mouth of the stream. On the last trip, only the recapture phase was conducted; the last trip occurred when most of the spawners were dead or dying.

In Thoms Lake, all mark-recapture and stream counts were conducted in East Creek. Mark-recapture and stream counts were conducted to a point on the stream where gradient increases and no more fish were present, approximately 2 km from the mouth. In Salmon Bay Lake, all mark-recapture and stream counts were conducted in the two major tributaries referred to as southwest head (Stream A) and south head (Stream B). Counts and recapture efforts were conducted as far as was feasible on each stream in a single day. In Luck Lake, all mark-recapture and stream counts were conducted in Luck Creek. Mark-recapture and stream counts were conducted in the mainstem up to the partial barrier falls approximately 2.5 km up stream from the mouth. Additional mark-recapture and stream counts were conducted on the tributary to Luck Creek that enters from the east approximately 1 km above the mouth. Survey efforts on that tributary continued to a barrier falls approximately 2 km upstream from the confluence or until no fish were present.

### Data Analysis

Darroch maximum-likelihood and least-squares, Schaefer population, and "pooled Petersen" estimates were calculated with the Stratified Population Analysis System (SPAS) software (Arnason et al. 1996; for details, refer to www.cs.umanitoba.ca/~popan/). SPAS had the advantage of allowing us to pool together some or all of the capture or recapture strata to get a more precise estimate of escapement, possibly at the expense of some bias. However, the pooled Petersen estimate can be biased when the assumptions of equal probability of capture are violated. Briefly stated, the three assumptions of equal probability of capture are: 1) all fish have an equal probability of capture in the first event, 2) all fish have an equal probability of capture in the second event, and 3) fish mix completely between the first and second event. SPAS provides a series of $X^2$ tests to look for obvious signs that these assumptions had failed. Arnason et al. (1996) go into a great deal of detail about their strategy for pooling strata based on significance testing. If only one of the test statistics was significant ($p \leq 0.05$), then we considered this to be insufficient evidence of a problem with the pooled Petersen estimate, and considered that partial or complete pooling to be valid. Other criteria we examined included checking to see if pooling produced big changes in the estimate of escapement. If pooling led to a small change, we concluded it was probably safe to pool. Using the $X^2$ tests in SPAS as guidelines, we attempted to pool as many strata as possible to increase precision.

When use of the pooled Petersen method was warranted, we used the following method to estimate the 95% confidence interval for the estimate, rather than the confidence interval estimate provided in the SPAS output. We let $K$ denote the number of fish marked in a random sample of a population of size $N$. We let $C$ denote the number of fish examined for marks at a later time, and let $R$ denote the number of fish in the second sample with a mark. Then the estimated number of fish in the entire population, $\hat{N}$, is given by:

$$\hat{N} = \frac{(K+1)(C+1)}{(R+1)} - 1 \qquad (1)$$

In this equation, $R$ is a random variable, and therefore so is the quantity $\hat{p} = \frac{R}{C}$. We can assume that $R$ follows a Poisson, binomial, hypergeometric, or normal distribution, depending on the circumstances of the sampling. We will let $\hat{p}$ be an estimate of the proportion of marked fish in the population, and assume it is normally distributed, with a variance given by $\text{var}(\hat{p}) = \frac{R}{C^2}$. We defined the confidence bounds for $p$ as ($a_{0.025}$, $a_{0.975}$), with $a_{0.025}$ and $a_{0.975}$ developed from the appropriate normal distribution. Then the 95% confidence interval bounds for the Petersen population estimate, $N^*$, were found by taking reciprocals of the confidence interval bounds for $p$ and multiplying by $K$. That is, the confidence bounds for the Petersen estimate are given by:

$$\left( K \cdot \frac{1}{a_{0.975}},\ K \cdot \frac{1}{a_{0.025}} \right). \tag{2}$$

## SOCKEYE ESCAPEMENT AGE AND LENGTH DISTRIBUTION

Over 600 length, sex and scales samples from adult sockeye salmon were collected at each lake during the spawning season to describe the size and age structure of the population, by sex. The length of each fish was measured from mid-eye to tail fork and to the nearest millimeter (mm). The sex of the fish was decided by the length and shape of the kype or jaw. Three scales were taken from the preferred area of each fish (INPFC 1963), and prepared for analysis as described by Clutter and Whitesel (1956). Scale samples were aged at the ADF&G Salmon Aging Laboratory in Douglas, Alaska. Age classes were designated following the European aging system where freshwater and saltwater years are separated by a period (e.g. 1.3 denotes a 5-year fish spending 1 year freshwater and 3 years saltwater). The proportion of age-sex group was estimated along with its associated standard error, using standard statistical techniques assuming a binominal distribution, described in common references, such as Thompson (1992).

## SOCKEYE FRY POPULATION ESTIMATES

In the past, we failed to produce statistically reliable estimates of the size of the sockeye fry population in lakes that had comparable numbers of similarly sized fish of other species, especially when the overall density of small fish was low. That is, when we had trouble collecting a large sample of small fish targets, we had difficulty in estimating the fraction of these targets that were sockeye fry. Consequently, we decided to only survey those lakes in 2003 that had samples of small fish targets over 200 fish in previous years. In 2003, the only lake of these three that met this criterion was Luck Lake. We used hydroacoustic and mid-water trawl sampling methods to describe the distribution of small pelagic fish and to estimate the abundance of sockeye salmon fry in 2003. To control year-to-year variation in our estimates, we conducted the acoustic survey in 2003 using the same fourteen transects (two transects in each of the seven sample sections) that were randomly chosen in 2002.

### Hydroacoustic survey

During the acquisition of acoustic targets, we surveyed each selected transect from shore to shore, beginning and ending the sampling at the depth of 10 m. Sampling was conducted during the darkest part of the night. A constant boat speed of about 2.0 m · $sec^{-1}$ was attempted for all transects. The acoustic equipment used on the survey was the Biosonics DT-4000™ scientific echosounder (420 kHz, 6° single beam transducer) and version 4.0.2 of the Biosonics Visual Acquisition© software was used to collect and record the data. The ping rate was set at 5 pings · $sec^{-1}$ and the pulse width at 0.4 ms. Only target strengths ranging from –40 dB to –68 dB were recorded because this range represented fish within the size range of juvenile sockeye salmon and other small pelagic fish.

## Trawl Sampling

Midwater trawl sampling was conducted in conjunction with hydroacoustic surveys to determine species composition of pelagic fish and age distribution of sockeye fry. A 2 m x 2 m elongated beam-trawl net with a cod-end was used for trawl sampling. Trawl sampling was conducted in the area of the lake with highest concentration of fish, identified during the hydroacoustic survey. Within this area, replicate tows were conducted at two depths. The second tow, at a given depth, was started at the termination point of the first tow. Direction of the second tow, for each depth, was selected so a different area from the first tow would be sampled. Trawl duration was 7–10 minutes, depending on target density and lake depth. If warranted, a second complete set of tows was conducted in a morphologically distinct section of the lake or in a second area of high fish density.

All adult fish caught in the midwater trawl were identified, counted, and released. All small fish from the trawl net were euthanized with MS 222. Fish were preserved with 90% alcohol. Samples from each tow were preserved in separate bottles. The bottle was labeled with the date, lake name, tow number, tow depth, time of tow, and initials of collectors.

In the laboratory, fish were re-hydrated by soaking in water for 60 minutes prior to measurement. All fish were identified to species, and snout-fork length (to the nearest millimeter) and weight (to the nearest 0.1 gram) were measured on each fish. All sockeye salmon fry under 50 mm were assumed to be age-0. Scales were collected from sockeye fry over 50 mm and mounted onto a microscope slide for age determination. Sockeye fry scales were examined through a Carton microscope with a video monitor and aged using methods outlined in Mosher (1968). Two trained technicians independently aged each sample. Results of each independent scale ageing were compared. In instances of discrepancy between the two age determinations, a third independent examination was conducted.

The proportion of each species caught in the trawls was used to allocate hydroacoustic target estimates by species; the estimate of sockeye fry was further allocated according to proportion of sockeye fry in each age class. The process of capturing juvenile fish with a trawl was modeled with a hieratical Bayesian model, assuming a separate random rate for each category of sonar target, with each trawl pass.  Rates of sockeye acquisition for each specific trawl pass were assumed to follow a Beta sampling distribution with a common set of parameters for the whole lake.

## Data Analysis

The sonar record was analyzed with Biosonics Visual Analyzer © version 4.0.2 software. Echo integration was used to generate an estimate of target density (targets $\cdot$ $m^{-2}$) for each sample transect (MacLennand and Simmonds 1992). Recall that the lake was divided into sample sections, with two transects per section. Mean target density for each section was estimated using the two replicate target density estimates. In each section, a sample variance for this estimate was calculated with one-degree of freedom using the two replicate observations. The mean target density for the whole lake was estimated as the average of target density estimates for each section, weighted by surface area of each section. The size of target population for each sample section was estimated as the product of mean target density and surface area for each section. The estimate of total targets in the lake was estimated as the sum of target population estimates for each section. Because each section was sampled independently from other sections, the estimated sampling variance for the whole-lake target population estimate was simply the sum of sample variances for each section. Sampling error was measured and reported as a coefficient of variation (CV; Sokal and Rohlf 1987). The estimate of total targets was partitioned into two categories, sockeye salmon and other small fish, by means of the trawl-net sampling.

We know from previous experience with many sockeye-producing lakes that number of sockeye salmon in a trawl sample is often much more variable than the usual binomial sampling model predicts. Thus in practice, the usual binomial confidence intervals can be very biased, and far too short.

We developed the following Bayesian procedure to measure uncertainty in the estimated proportion of sockeye salmon. Let $T$ denote the total targets in the lake, and let $\hat{T}$ denote the usual sampling-based estimate of $T$, derived from the echo integration analysis of the sonar record. Conditioned on total number of fish caught in the $i^{th}$ trawl sample, we let number of sockeye salmon in each trawl follow a binomial sampling law. We denote trawl sample size as $n_i$ and we denote number of sockeye salmon in this sample as $y_i$. We let parameter $p_i$ denote the unknown underlying proportion of sockeye salmon in the $i^{th}$ trawl sample, and we assume $p_i$ is a key parameter in the sampling distribution of $y_i$. We assume each trawl sample has its own sampling distribution, possibly different from any other in the lake. Next, we suppose that $p_i$ is itself drawn from a beta probability distribution with mean $p_\mu = \dfrac{\alpha}{\alpha + \beta}$.

In other words, let $y_i$ be distributed as a binominal random variable with parameters $p_i$ and $n_i$ and let $p_i$ follow a beta probability distribution with parameters $\alpha$ and $\beta$. Again, $\alpha$ and $\beta$ are the same for each transect in the lake at the occasion of trawl sampling. The hyperparameters, $\alpha$ and $\beta$, can be estimated through all of the samples from each trawl haul, by Bayesian conditioning on all of the outcomes.

We chose a uniform distribution between 0 and 10 for both $\alpha$ and $\beta$ parameters after experimenting with this distribution and truncated normal distributions. This prior distribution limits influence of prior distributions on posterior distributions, and ensures data have adequate influence once sample size is large. For example, for sample sizes less than 10, the posterior distribution will be almost entirely controlled by prior distribution. However, for sample sizes approaching 100 prior distribution will have little influence on mean posterior distribution for each individual $p_i$, although this prior can lead to some unreasonable estimates of $p$. We note that if posterior probability is allowed to build up on larger and larger values of $\alpha$ and $\beta$, posterior means of each $p_i$ will become more alike, and posterior variance of $p$ overall will decline unrealistically. Therefore, limiting maximum values of both $\alpha$ and $\beta$ to 10 seems to provide a compromise between allowing posterior means of individual $p_i$'s to be either alike or unalike, and still allow data (likelihood) to dominate posterior distribution.

The Bayesian posterior distribution of unknown parameter $p$ was generated numerically using the Markov Chain Monte Carlo method. To compare and combine an estimate of $T$ in the same context as Bayesian posterior mean of the distribution of $p$, we assumed a posterior distribution of $T$ would be approximately normal distributed, both with mean and variance approximated by sample mean and variance of the sampling-based estimate. We then generated at least 5,000 random draws this approximate normal distribution. We previously generated 5,000 observations of posterior distribution of $p$. Denoting each random draw with subscript $j$, we calculated a random draw from posterior distribution of $S$ as $S_j = p_j T_j$. From there we noted mean of the posterior distribution of $S$ the simulated values, from $j = 1, ..., 5{,}000$. We generated 95% credible intervals—the Bayesian counterpart to a confidence interval—using 2.5 and 97.5 percentiles of posterior distributions of *S*. All analyses were performed with the Wingbugs software.

## LIMNOLOGY SAMPLING

Limnology sampling was conducted at two stations (A and B) on each lake five times between May and October to estimate euphotic zone depth, to record dissolved oxygen and temperature values by depth and to collect zooplankton samples. Light, temperature and dissolved oxygen profiles were collected at the primary sample site, Station A. One zooplankton sample was collected at each station on each lake.

### Light, Temperature, and Dissolved Oxygen Profiles

Underwater light intensity was recorded from just below the surface to the depth where measured intensity was one percent of the surface light reading, at 0.5 m intervals, using an electronic light sensor and meter (Protomatic). The vertical light extinction coefficients ($K_d$) were estimated as the slope of the light intensity (natural log of percent subsurface light) versus depth. The euphotic zone depth (EZD) was defined as the depth to which one percent of the subsurface light [photosynthetically available radiation (400–700 nm)] penetrates the lake surface (Schindler 1971), and was calculated from the equation, EZD = 4.6205 / $K_d$ (Kirk 1994). The product of the euphotic zone depth and the surface area provided an estimate of the volume of the lake in which is photosyntheticly active.

Temperature and dissolved oxygen (DO) profiles were measured with a Yellow Springs Instruments (YSI) Model 58 DO meter and probe, in relative (percent of saturation) and absolute (mg $L^{-1}$) values for DO and in ºC for temperature. Measurements were made at 1 m intervals to the first 10 m or the lower boundary of the thermocline (defined as the depth at which the change in temperature decreased to less than 1 ºC per meter), and thereafter at 5 m intervals to within 2 m of the bottom (or 50 m). The dissolved oxygen meter reading at 1 m was calibrated at the beginning of a sampling trip using the value from a 60 ml Winkler field titration (Koenings et al. 1987). The DO profile was measured only on the first sampling trip in May because in 2001 we found no major changes in DO profiles during the summer and early fall season.

### Secondary Production

Zooplankton are the primary food for sockeye salmon and cladocerans are their preferred food within the zooplankton community. By estimating the number and biomass and number of zooplankton by genus or species throughout the season, we can observe how the species composition changes over the season and between years. Zooplankton samples were collected at two stations (A and B) using a 0.5 m diameter, 153 um mesh, 1:3 conical net. Vertical zooplankton tows were pulled from a maximum depth of 50 m, or 2 m from the bottom of the lake if shallower than 50 m, at a constant speed of 0.5 m sec-1. The net was rinsed prior to removing the organisms, and all specimens were preserved in neutralized 10% formalin (Koenings et al. 1987). Zooplankton samples were analyzed at the ADF&G Commercial Fisheries Limnology Laboratory in Soldotna, Alaska. Identification to genus or species, enumeration, and density and biomass estimates were performed as in 2001 and 2002 (Conitz et al. 2002; Koenings et al. 1987). Zooplankton density (individuals per $m^2$ surface area) and biomass (weight per $m^2$ surface area) were estimated by species and by the sum of all species (referred to as total zooplankton density or biomass).

# RESULTS

## SOCKEYE ESCAPEMENT ESTIMATES

### Thoms Lake

A total of 500 sockeye salmon were marked and released at the mouth of Thoms Creek in 2003, in two sampling events: 26 August and 7 September (Table 1). During the recovery phase, 1,545 sockeye salmon were examined in Thoms Creek for marks in two sampling events: 9 September and 24 September. Of these, 57 fish had marks. From these samples we developed a pooled Petersen estimate of 11,000 sockeye spawners (95% CI: 9,000–15,000; CV = 12%). We detected no violations of the assumptions of complete mixing or equal probability of capture in the second event ($X^2 = 0.85$, $df = 1$; $p = 0.36$). Capture probabilities were different between strata for fish marked in the first event ($X^2 = 17.16$, $df = 1$; $p \leq 0.001$). Because at least one of the consistency tests passed (i.e. $p > 0.05$), we decided to use the pooled Petersen estimate to increase precision. Although our study only encompassed Thoms Creek, we did not observe spawning sockeye salmon in any beach areas or tributary except Thoms Creek, where the mark-recapture sampling was conducted. Therefore, we assumed that our estimate most likely represents the total escapement for this lake. Similar to 2002, the highest stream survey counts occurred at the end of August and the beginning of September (Table 2).

**Table 1.–**Marking and recapture sample sizes, and numbers of marked fish in recapture strata from Thoms Lake sockeye salmon mark-recapture studies, 2003.

| Marking date | Mark Type | Number of fish released with marks | Number of marked fish recovered: 9-10 Sep | 24-25 Sep | Total |
|---|---|---|---|---|---|
| 26-27 Aug | Triangle | 119 | 10 | 6 | 16 |
| 7-10 Sep | Square | 381 | 0 | 41 | 41 |
| Total number of fish marked | | 500 | | | |
| Number of marked fish recovered | | | 10 | 47 | 57 |
| Number of fish examined for marks | | | 683 | 794 | 1,545 |

**Table 2.–**Thoms, Luck, and Salmon Bay lake adult sockeye salmon escapement counts in 2003 from foot surveys by location and date. The counts represent an average between three observers. Individual counts from each observer were not recorded.

| Stream | Date | Number of Sockeye Salmon |
|---|---|---|
| East Creek, Thoms Lake | 11-Aug | 0 |
| | 27-Aug | 2,000 |
| | 7-Sep | 1,800 |
| | 24-Sep | 100 |
| Three unnamed inlet steams, Salmon Bay Lake | 10-Aug | 0 |
| | 25-Aug | 300 |
| | 16-Sep[a] | 3,115[b] |
| | 21-Sep | 182 |
| Luck Creek, Luck Lake | 8-Aug | 0 |
| | 22-Aug | 2,049 |
| | 5-Sep | 5,380 |
| | 22-Sep | 1,000 |
| | 3-Oct | 120 |

[a] Petersburg ADF&G personnel conducted this foot survey.

[b] 110 sockeye salmon carcasses were also observed on 16 September.

## Salmon Bay Lake

A total of 681 sockeye salmon were marked and released at the mouth of the two major tributaries, on two sampling occasions: 23 August and 20 September (Table 3). During the recovery phase, 817 sockeye salmon were examined for marks during four sampling events and only three fish had a mark. High water hampered efforts to examine more fish and severe weather conditions prevented us from sampling at the beginning of September, resulting in inadequate recoveries of marked fish. Consequently, we were unable to estimate the number of sockeye spawners in 2003. Similar to 2002, the peak count during stream surveys occurred mid-September (Table 2).

**Table 3.–**Marking and recapture sample sizes and numbers of marked fish found in Salmon Bay Lake sockeye salmon mark-recapture studies, 2003.

| Marking date | Mark type | Number of fish released with marks | Number of marked fish recovered 25-Aug | 20-Sep | 21-Sep | Total |
|---|---|---|---|---|---|---|
| 23-25 Aug | Triangle | 656 | 1 | 0 | 2 | 3 |
| 20-21 Sep | Square | 25 | 0 | 0 | 0 | 0 |
| Total number of fish marked | | 681 | | | | |
| Number of marked fish recovered | | | 1 | 0 | 2 | 3 |
| Number of fish examined for marks | | | 20 | 31 | 766 | 817 |

## Luck Lake

Although a total of 502 sockeye salmon were marked and released in Luck Lake during three sampling occasions on 21 August, 6 September, and 22 September (Table 4), we were unable to develop a statistically defendable escapement estimate for this system. During the recovery phase, we examined 1,862 sockeye salmon in Luck Creek on three sampling events and 49 of these fish were marked. The last marking stratum, corresponding to fish marked on 22 September, was dropped since only 11 fish were released and no recoveries of that specific mark were made (Table 4). The small number of fish marked and released on 22 September indicated there were few fish remaining at the mouth of the stream ready to enter the spawning population. Similar to 2002, the peak survey count occurred during the first week of September (Table 2).

However, we failed to meet the assumptions of complete mixing and equal probability of capture for the Petersen mark-recapture estimate ($X^2$ = 52.08, $df$ = 1, $p \leq 0.001$). The capture probabilities appear to have been different among strata for fish marked in the first event ($X^2$ = 9.24, $df$ = 2, $p$ = 0.01). Since neither of the consistency tests passed ($p < 0.05$), there is almost surely some level of bias in the pooled Petersen estimate of 19,000. As an alternative, the maximum-likelihood Darroch method produced an estimate of 24,000 fish. Here again, the assumptions of equal catchability appear to have been violated ($G^2$ = 7.58, $df$ = 1, $p$ = 0.01).

**Table 4.–**The number of fish marked, examined for marks, and the number of marks observed in the mark-recapture study at Luck Lake in 2003.

| Marking date | Mark type | Number of fish released with marks | Number of marked fish recovered 5-Sep | 22-23 Sep | 2-Oct | Total |
|---|---|---|---|---|---|---|
| 21-22 Aug | Triangle | 300 | 4 | 1 | 0 | 9 |
| 6-Sep | Square | 191 | 0 | 19 | 21 | 40 |
| 22-Sep | Dbl Round | 11 | 0 | 0 | 0 | 0 |
| Total number of fish marked | | 502 | | | | |
| Number of marked fish recovered | | | 4 | 20 | 21 | 49 |
| Number of fish examined for marks | | | 249 | 452 | 1,098 | 1,862 |

## SOCKEYE ESCAPEMENT AGE AND LENGTH DISTRIBUTION

### Thoms Lake

In 2003, we sampled a total of 482 adult sockeye salmon from Thoms Lake for sex and length, and we collected scales for aging. Scale pattern analysis showed that age-2.2 fish dominated both sexes of adult sockeye salmon at 46% ($n$ = 223) of this sample, followed by 29% age-2.3 fish ($n$ = 141; Table 5). Age-1.1 ($n$ = 12) and age-2.1 ($n$ = 35) jacks comprised 14% of the sample, which is similar to the last 21 years (16%; Table 5; Appendix A3). The overall sex ratio was 65% male to 35% female. The mean fork length was 518 mm (SE = 1.4 mm, $n$ = 221) for age-2.2 fish and 569 mm (SE = 1.6 mm, $n$ = 141) for age-2.3 fish (Table 6).

**Table 5.–**Age composition of sockeye salmon in Thoms Lake escapement by sex, brood year, and age class, 27 August to September 27, 2003. Std. Error represents the standard error of the percent measure in each age class.

| Brood Year | 2000 | 1999 | 1999 | 1998 | 1998 | 1997 | |
|---|---|---|---|---|---|---|---|
| **Age** | **1.1** | **1.2** | **2.1** | **1.3** | **2.2** | **2.3** | **Total** |
| **Male** | | | | | | | |
| Sample Size | 12 | 28 | 35 | 14 | 144 | 79 | 312 |
| Percent | 2.5 | 5.8 | 7.3 | 2.9 | 29.9 | 16.4 | 64.7 |
| Std. Error | 0.7 | 1.1 | 1.2 | 0.8 | 2.1 | 1.7 | 2.2 |
| **Female** | | | | | | | |
| Sample Size | | 15 | | 14 | 79 | 62 | 170 |
| Percent | | 3.1 | | 2.9 | 16.4 | 12.9 | 35.3 |
| Std. Error | | 0.8 | | 0.8 | 1.7 | 1.5 | 2.2 |
| **All Fish** | | | | | | | |
| Sample Size | 12 | 43 | 35 | 28 | 223 | 141 | 482 |
| Percent | 2.5 | 8.9 | 7.3 | 5.8 | 46.3 | 29.3 | 100.0 |
| Std. Error | 0.7 | 1.3 | 1.2 | 1.1 | 2.2 | 2.0 | |

**Table 6.–**Mean fork length (mm) of sockeye salmon in Thoms Lake escapement by sex, brood year, and age class, sampled from 27 August to 27 September, 2003.

| **Brood Year** | **2000** | **1999** | **1999** | **1998** | **1998** | **1997** | |
|---|---|---|---|---|---|---|---|
| **Age** | **1.1** | **1.2** | **2.1** | **1.3** | **2.2** | **2.3** | **Total** |
| **Male** | | | | | | | |
| Length (mm) | 359 | 498 | 361 | 575 | 520 | 569 | 509 |
| Std. Error | 5.9 | 5.6 | 3.3 | 5.2 | 1.8 | 2.2 | 4 |
| Sample Size | 12 | 28 | 35 | 14 | 142 | 79 | 310 |
| **Female** | | | | | | | |
| Length (mm) | | 502 | | 579 | 515 | 569 | 539 |
| Std. Error | | 6.5 | | 5.1 | 2.4 | 2.3 | 2.7 |
| Sample Size | | 15 | | 14 | 79 | 62 | 170 |
| **All Fish** | | | | | | | |
| Length (mm) | 359 | 500 | 361 | 577 | 518 | 569 | 519 |
| Std. Error | 5.9 | 4.3 | 3.3 | 3.6 | 1.4 | 1.6 | 2.8 |
| Sample Size | 12 | 43 | 35 | 28 | 221 | 141 | 480 |

## Salmon Bay Lake

In 2003, we sampled a total of 366 adult sockeye salmon from Salmon Bay Lake for sex and length, and we collected scales for aging. Similar to the age composition of the last 21 years, scale pattern analysis showed that the dominant age class of adult sockeye salmon was age 1.3, at 73% (*n* = 267) of this sample, followed by age 1.2 (*n* = 74) at 20% of the sample (Table 7; Appendix A4). The overall sex ratio was 67% male to 33% female. The mean fork length was 571 mm (SE = 1.6 mm, *n* = 261) for age-1.3 fish and 483 mm (SE = 4.0 mm, *n* = 73) for age-1.2 fish (Table 8).

**Table 7.–**Age composition of sockeye salmon in Salmon Bay Lake escapement by sex, brood year, and age class, sampled from 10 August to 6 September, 2003.

| **Brood Year** | **2000** | **1999** | **1998** | **1998** | **1997** | |
|---|---|---|---|---|---|---|
| **Age** | **1.1** | **1.2** | **1.3** | **2.2** | **2.3** | **Total** |
| **Male** | | | | | | |
| Sample Size | 6 | 66 | 158 | 5 | 10 | 245 |
| Percent | 1.6 | 18.0 | 43.2 | 1.4 | 2.7 | 66.9 |
| Std. Error | 0.7 | 2.0 | 2.6 | 0.6 | 0.8 | 2.4 |
| **Female** | | | | | | |
| Sample Size | | 8 | 109 | 1 | 3 | 121 |
| Percent | | 2.2 | 29.8 | 0.3 | 0.8 | 33.1 |
| Std. Error | | 0.8 | 2.4 | 0.3 | 0.5 | 2.4 |
| **All Fish** | | | | | | |
| Sample Size | 6 | 74 | 267 | 6 | 13 | 366 |
| Percent | 1.6 | 20.2 | 73.0 | 1.6 | 3.6 | 100.0 |
| Std. Error | 0.7 | 2.1 | 2.3 | 0.7 | 1.0 | |

**Table 8.–**Mean fork length (mm) of sockeye salmon in Salmon Bay Lake escapement by sex, brood year, and age class, sampled from 10 August to 6 September, 2003.

| Brood Year | 2000 | 1999 | 1998 | 1998 | 1997 | |
|---|---|---|---|---|---|---|
| **Age** | **1.1** | **1.2** | **1.3** | **2.2** | **2.3** | **Total** |
| **Male** | | | | | | |
| Length (mm) | 361 | 481 | 583 | 455 | 578 | 547 |
| Std. Error | 12.9 | 4.4 | 1.7 | 10.8 | 6.6 | 4 |
| Sample Size | 6 | 65 | 156 | 5 | 9 | 241 |
| **Female** | | | | | | |
| Length (mm) | | 494 | 552 | 475 | 550 | 548 |
| Std. Error | | 4.7 | 2.1 | | 25.2 | 2.5 |
| Sample Size | | 8 | 105 | 1 | 3 | 117 |
| **All Fish** | | | | | | |
| Length (mm) | 361 | 483 | 571 | 458 | 571 | 547 |
| Std. Error | 12.9 | 4 | 1.6 | 9.5 | 8.1 | 2.8 |
| Sample Size | 6 | 73 | 261 | 6 | 12 | 358 |

## Luck Lake

In 2003, we sampled a total of 551 adult sockeye salmon from Luck Lake for sex and length, and we collected scales for aging. Although, in 2003 scale pattern analysis showed that the dominant age class of adult sockeye salmon was age 1.3, at 45% ($n$ = 247) of the sample, followed by age 1.2 at 20% ($n$ = 111) of the sample, in the past 21 years, the age classes 1.2 and 1.3 comprised similar proportions of samples (Table 9). Age-1.1 ($n$ = 53) and age-2.1 ($n$ = 35) jacks comprised 16% of the sample (Table 9). The sex ratio was 50.5% male to 49.5% female. The mean fork length was 566 mm (SE = 1.4 mm, $n$ = 247) for age-1.3 fish and 466 mm (SE = 2.6 mm, $n$ = 111) for age-1.2 fish (Table 10).

**Table 9.–**Age composition of sockeye salmon in Luck Lake escapement by sex, brood year, and age class, sampled from 8 August to 2 October, 2003.

| Brood Year | 2000 | 1999 | 1999 | 1998 | 1998 | 1997 | |
|---|---|---|---|---|---|---|---|
| **Age** | **1.1** | **1.2** | **2.1** | **1.3** | **2.2** | **2.3** | **Total** |
| Male | | | | | | | |
| Sample Size | 53 | 98 | 35 | 40 | 46 | 6 | 278 |
| Percent | 9.6 | 17.8 | 6.4 | 7.3 | 8.3 | 1.1 | 50.5 |
| Std. Error | 1.2 | 1.6 | 1.0 | 1.1 | 1.2 | 0.4 | 2.1 |
| **Female** | | | | | | | |
| Sample Size | | 13 | | 207 | 18 | 35 | 273 |
| Percent | | 2.4 | | 37.6 | 3.3 | 6.4 | 49.5 |
| Std. Error | | 0.6 | | 2.0 | 0.7 | 1.0 | 2.1 |
| **All** | | | | | | | |
| Sample Size | 53 | 111 | 35 | 247 | 64 | 41 | 551 |
| Percent | 9.6 | 20.1 | 6.4 | 44.8 | 11.6 | 7.4 | 100.0 |
| Std. Error | 1.2 | 1.7 | 1.0 | 2.1 | 1.3 | 1.1 | |

**Table 10.–**Mean fork length (mm) of sockeye salmon in Luck Lake escapement by sex, brood year, and age class, sampled from 8 August to 2 October 2003.

| Brood Year | 2000 | 1999 | 1999 | 1998 | 1998 | 1997 | |
|---|---|---|---|---|---|---|---|
| **Age** | **1.1** | **1.2** | **2.1** | **1.3** | **2.2** | **2.3** | **Total** |
| **Male** | | | | | | | |
| Length (mm) | 347 | 460 | 371 | 581 | 465 | 569 | 448 |
| Std. Error | 2.3 | 2.3 | 4.2 | 3.3 | 3.8 | 7.5 | 4.7 |
| Sample Size | 53 | 98 | 34 | 40 | 46 | 6 | 277 |
| **Female** | | | | | | | |
| Length (mm) | | 512 | | 563 | 499 | 562 | 556 |
| Std. Error | | 3.6 | | 1.5 | 7.4 | 3.1 | 1.7 |
| Sample Size | | 13 | | 207 | 18 | 35 | 273 |
| **All Fish** | | | | | | | |
| Length (mm) | 347 | 466 | 371 | 566 | 475 | 563 | 502 |
| Std. Error | 2.3 | 2.6 | 4.2 | 1.4 | 3.9 | 2.9 | 3.4 |
| Sample Size | 53 | 111 | 34 | 247 | 64 | 41 | 550 |

## SOCKEYE FRY ASSESSMENT

Hydroacoustic surveys for Thoms and Salmon Bay Lakes were not conducted in 2003 due to our inability to obtain adequate trawl samples in 2002 and 2001. We did, however, perform a hydroacoustic survey on Luck Lake in 2003.

### Luck Lake

A Hydroacoustic survey and mid-water trawl sampling were conducted on 7 August 2003. The usual sampling-based estimate of total targets was 176,300 (SE = 7,000, CV = 4%). Species apportionment was based on results of five 10–15-min trawl tows, with a total sample of 119 fish (Table 11). Combining all fish in the trawls to get the proportion of sockeye fry, similar to previous years, results in 87% of the sample being assigned to sockeye fry. The sockeye fry occurred in two age classes, with a bimodial size distribution (Figure 5). The Bayesian posterior mean of the distribution of the proportion of sockeye targets was 85% and the mean estimate of all targets in the lake was 176,400 (Table 12). The product of the posterior means of $p$ and $T$ (total targets) equals 150,000 fry, which we took as our official estimate of the number of juvenile sockeye salmon in the lake (95% credible interval 122,000 to 172,000 fry; Table 12). The sockeye fry density was 14 fry per 100 $m^2$, (95% credible interval of 11–16 fry per 100 $m^2$). Considering all sources of uncertainty, we feel it is safe to conclude that the posterior coefficient of variation for the sockeye fry estimate was less than 8% (i.e., posterior standard deviation divided by posterior mean of sockeye fry), meaning that we met our precision objective for the hydroacoustic survey.

**Table 11.–**Summary of Luck Lake tow netting results by tow, depth (m), time duration (min), species and sample size in 2003.

| Tow | Depth (m) | Duration of tow (min) | Species-age | Number of fish |
|---|---|---|---|---|
| 1 | 8 | 15 | sockeye age-0 | 37 |
| | | | sockeye age-1 | 5 |
| 2 | 8 | 15 | | 0 |
| 3 | 10 | 10 | sockeye age-0 | 8 |
| | | | sockeye age-1 | 7 |
| | | | stickleback | 3 |
| | | | sculpin | 1 |
| 4 | 10 | 15 | sockeye age-0 | 23 |
| | | | sockeye age-1 | 5 |
| | | | stickleback | 2 |
| 5 | 7 | 15 | sockeye age-0 | 17 |
| | | | sockeye age-1 | 5 |
| | | | stickleback | 6 |
| Total number of sockeye fry | | | | 107 |
| Total number of fish | | | | 119 |

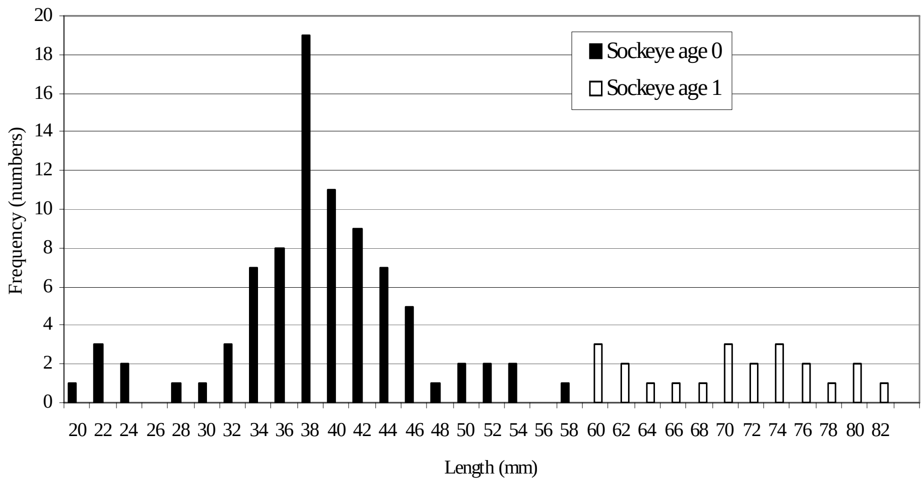


**Figure 5.–**Length frequency distribution of sockeye fry caught in the Luck Lake mid-water trawl 2003.

**Table 12.**–Bayesian estimates of the proportion of small fish in Luck Lake, at the time of the 2003 hydroacoustic survey, that were sockeye fry.

| Parameter/Estimate | Sample Size | Mean | Standard error | 2.50 Percent | 97.50 Percent | Median |
|---|---|---|---|---|---|---|
| $p_1$ | 42 | 0.978 | 0.023 | 0.918 | 0.999 | 0.985 |
| $p_2$ | 19 | 0.807 | 0.077 | 0.632 | 0.934 | 0.814 |
| $p_3$ | 30 | 0.917 | 0.046 | 0.806 | 0.983 | 0.926 |
| $p_4$ | 28 | 0.798 | 0.068 | 0.65 | 0.912 | 0.804 |
| $p_\mu$ | | **0.85** | **0.065** | **0.7** | **0.95** | **0.859** |
| Total target estimate | | 176,000 | 6,900 | 163,000 | 190,000 | 176,000 |
| Total sockeye fry estimate | | 150,000 | 12,900 | 122,000 | 172,000 | 151,000 |

Note: Based on 5 trawl samples (one trawl sample did not catch any fish and was dropped from the analysis). Distributions of the proportion of sockeye fry simulations are represented by the posterior mean proportions ($p_i$), standard error, and the lower (2.5%) and upper (97.5%) credible intervals for each of the 4 trawl samples, and an overall proportion, $p_\mu$ for the whole lake, together with the descriptions of the posterior distributions of the total hydroacoustic targets, and the number of targets that were sockeye fry.

Interestingly, the posterior standard deviation of the parameter $p_\mu$ is about twice as large as the usual sampling-based estimate of standard error of the estimate. This is partially a function the dissimilarity of sample proportions of sockeye fry in each of the four trawl tows**.**

## LIMNOLOGY

### Vertical Light Penetration, Temperature, and Dissolved Oxygen

Light penetration was measured in Thoms, Salmon Bay, and Luck Lakes on 8 May, 6 June, 1 July, 26 Aug (Thoms only), 23 Aug (Salmon Bay only), 22 Aug (Luck only), 8 Oct (Thoms only), and 10 Oct (Salmon Bay and Luck), at Station A in 2003. The euphotic zone depth fluctuated very little throughout the season with the exception of Salmon Bay Lake in May and Luck Lake in August (Table 13). The mean euphotic zone depth in Thoms Lake was about a meter less than Salmon Bay Lake (3.8 m) and Luck Lake (3.7 m) most likely due to more tannin in the water, compared to the other two lakes (Table 13).

**Table 13.–**Euphotic zone depth in meters for Thoms, Salmon Bay, and Luck lakes by date and a seasonal mean for each lake in 2003.

| Lake | May | June | July | August | October | Seasonal Mean |
|---|---|---|---|---|---|---|
| Thoms | 2.9 | 3.2 | 2.7 | 2.7 | 2.3 | 2.8 |
| Salmon Bay | 4.4 | 3.2 | 3.9 | 4.1 | 3.7 | 3.8 |
| Luck | 3.9 | 3.7 | 3.8 | 4.5 | 2.7 | 3.7 |

The depth of the thermocline in Thoms Lake was stable throughout most the season despite heavy rains and windy weather conditions in 2003 (Table 14). The thermocline was already formed in early May, increasing in range during the summer and becoming isothermic by the first week in October (Table 14; Appendix B1).

**Table 14.–**The 2003 upper and lower depth and range of the thermocline in Thoms Lake by sample date.

| Date | Upper (m) | Lower (m) | Range (m) |
|---|---|---|---|
| 8-May | 7 | 9 | 2 |
| 6-Jun | 8 | 11 | 3 |
| 1-Jul | 7 | 11 | 4 |
| 26-Aug | 7 | 12 | 5 |
| 7-Oct | no thermocline | | 0 |

The depth of the thermocline in Salmon Bay Lake was also stable during the summer months in 2003 (Table 15). However, the lake was stratified for a shorter period of time than Thoms Lake, remaining isothermic until late spring and becoming isothermic again by early October (Table 15; Appendix B2).

**Table 15.–**The 2003 upper and lower depth and range of the thermocline in Salmon Bay Lake by sample date.

| Date | Upper (m) | Lower (m) | Range (m) |
|---|---|---|---|
| 8-May | no thermocline | | 0 |
| 6-Jun | 6 | 8 | 2 |
| 1-Jul | 8 | 13 | 5 |
| 26-Aug | 9 | 12 | 3 |
| 7-Oct | no thermocline | | |

The thermocline in Luck Lake was not present except for one sample date in August (Table 16; Appendix B3). Despite the fact that Luck Lake (210 ha; maximum depth of 38 m) has a general morphology similar to Thoms Lake (153 ha; maximum depth of 33 m), less protection from wind and stormy weather in Luck Lake could account for the difference in thermocline patterns in these two lakes.

**Table 16.–**The 2003 upper and lower depth and range of the thermocline in Luck Lake by sample date.

| Date | Upper (m) | Lower (m) | Range (m) |
|---|---|---|---|
| 8-May | no thermocline | | 0 |
| 6-Jun | no thermocline | | 0 |
| 1-Jul | no thermocline | | 0 |
| 22-Aug | 7 | 12 | 5 |
| 10-Oct | no thermocline | | 0 |

## Secondary Production

Zooplankton samples were collected from Thoms, Salmon Bay, and Luck lakes on 8 May, 6 June, 1 July, 26 August (Thoms only), 23 August (Salmon Bay only), 22 August (Luck only), 8 October (Thoms only), and 10 October (Salmon Bay and Luck), at Stations A and B on each lake.

### Thoms Lake

Similar to previous years, the cladoceran *Bosmina* sp. dominated the zooplankton assemblage in numbers in Thoms Lake in 2003, followed by *Diaphanosoma* sp., another cladoceran not commonly seen in Southeast Alaska (Table 17; Appendix B4). The large bodied *Diaptomus* sp. had a higher total biomass than the *Bosmina* and *Diaphanosoma* due to their larger size (Table 17 and 18; Appendix B5). The dipteran insects, *Chaoborus* were present in small numbers in the zooplankton tows.

**Table 17.** –The 2003 mean weighted zooplankton densities and lengths by station and total lake estimates in Thoms Lake.

| | Mean weighted densities (number/m$^2$) | | | | | | Mean weighted length (mm) | | |
|---|---|---|---|---|---|---|---|---|---|
| **Zooplankton species** | **Sta. A Mean** | **Sta. A Percent** | **Sta. B Mean** | **Sta. B Percent** | **Lake Mean** | **Lake Percent** | **Sta. A Length** | **Sta. B Length** | **Lake Mean** |
| *Diaptomus* | 14,135 | 20% | 10,168 | 16% | 12,152 | 18% | 1.18 | 1.33 | 1.26 |
| *Ovig. Diaptomus* | 177 | 0% | 397 | 1% | 287 | 0% | 1.90 | 1.88 | 1.89 |
| *Cyclops* | 394 | 1% | 1,107 | 2% | 751 | 1% | 0.61 | 0.58 | 0.60 |
| *Bosmina* | 30,294 | 42% | 23,013 | 36% | 26,654 | 39% | 0.33 | 0.33 | 0.33 |
| *Ovig. Bosmina* | 883 | 1% | 693 | 1% | 788 | 1% | 0.39 | 0.40 | 0.39 |
| *Daphnia l.* | 3,087 | 4% | 3,851 | 6% | 3,469 | 5% | 0.55 | 0.54 | 0.54 |
| *Ovig. Daphnia l.* | 604 | 1% | 914 | 1% | 759 | 1% | 0.75 | 0.77 | 0.76 |
| *Diaphanosoma* | 16,329 | 23% | 16,770 | 27% | 16,550 | 24% | 0.49 | 0.52 | 0.50 |
| *Ovig. Diaphanosoma* | 238 | 0% | | | 1,498 | 2% | 0.62 | 0.67 | 0.65 |
| *Holopedium* | 3,019 | 4% | 2,758 | 4% | 1,761 | 3% | 0.50 | 0.48 | 0.49 |
| *Ovig. Holopedium* | 299 | 0% | 503 | 1% | 299 | 0% | 0.54 | 0.59 | 0.57 |
| *Polyphemus* | 442 | 1% | 584 | 1% | 513 | 1% | 0.48 | 0.51 | 0.50 |
| *Chaoborus* | 140 | 0% | 145 | 0% | 143 | 0% | | | |
| Copepod nauplii | 2,160 | 3% | 2,242 | 4% | 2,201 | 3% | | | |
| Total | 72,201 | | 63,145 | | 67,673 | | | | |

**Table 18.–**Thoms Lake zooplankton seasonal mean weighted biomass density (mg/m$^2$) and percent of total biomass, by species, at stations A and B and mean of values for both station.

| **Species** | **Station A** | **Percent** | **Station B** | **Percent** | **Mean** | **Percent** |
|---|---|---|---|---|---|---|
| *Diaptomus* | 98 | 60% | 97 | 59% | 97.0 | 60% |
| Ovig. *Diaptomus* | 5 | 3% | 10 | 6% | 7.5 | 5% |
| *Cyclops* | 0.49 | 0% | 1 | 1% | 0.7 | 0% |
| *Bosmina* | 29 | 18% | 22 | 13% | 25.5 | 16% |
| Ovig. *Bosmina* | 1 | 1% | 1 | 1% | 1.0 | 1% |
| *Daphnia l.* | 4 | 2% | 5 | 3% | 4.5 | 3% |
| Ovig. *Daphnia l.* | 2 | 1% | 2 | 1% | 2.0 | 1% |
| *Diaphanosoma* | 16 | 10% | 19 | 12% | 17.5 | 11% |
| Ovig. *Diaphanosoma* | 0 | 0% | 0 | 0% | 0.0 | 0% |
| *Holopedium* | 6 | 4% | 5 | 3% | 5.5 | 3% |
| Ovig. *Holopedium* | 1 | 1% | 2 | 1% | 1.5 | 1% |
| *Polyphemus* | 0.13 | 0% | 0.19 | 0% | 0.2 | 0% |
| **Total** | 162.6 | | 164.2 | | 162.9 | |

## Salmon Bay Lake

In 2003, the cyclopoids zooplankton accounted for almost 70% of the density of zooplankton in Salmon Bay Lake and the *Bosmina* comprised about 17% (Table 19; Appendix B6). However, the calanoid copepod, *Epischura*, surpassed the bosminids in biomass because of their larger size (Table 19 and 20; Appendix B7). Although the cladoceran, *Daphnia middendorffina,* was twice as big as other zooplankton, its numbers were so low as to not contribute substantially to the total biomass of zooplankton in Salmon Bay Lake in 2003 (Table 19 and 20). This large cladoceran was not present in the other two lakes in the Wrangell project.

**Table 19. –**The 2003 mean weighted zooplankton densities and lengths by station and total lake estimates in Salmon Bay Lake.

| | Mean weighted densities (number/m$^2$) | | | | | | Mean weighted length (mm) | | |
|---|---|---|---|---|---|---|---|---|---|
| **Zooplankton species** | **Sta. A Mean** | **Sta. A Percent** | **Sta. B Mean** | **Sta. B Percent** | **Lake Mean** | **Lake Percent** | **Sta. A Length** | **Sta. B Length** | **Lake Mean** |
| *Epischura* | 13,279 | 5% | 6,938 | 5% | 10,109 | 5.4% | 1.11 | 1.14 | 1.12 |
| *Diaptomus* | - | 0% | - | 0% | - | 0.0% | 0.66 | 0.65 | 0.66 |
| *Cyclops* | 164,391 | 68% | 92,940 | 70% | 128,665 | 68.5% | 0.88 | 0.87 | 0.87 |
| Ovigerous *Cyclops* | 1,715 | 1% | 1,797 | 1% | 1,756 | 0.9% | 0.33 | 0.36 | 0.34 |
| *Bosmina* | 44,269 | 18% | 17,850 | 13% | 31,060 | 16.5% | 0.41 | 0.43 | 0.42 |
| Ovigerous *Bosmina* | 2,276 | 1% | 1,410 | 1% | 1,843 | 1.0% | 0.72 | 0.64 | 0.68 |
| *Daphnia l.* | 6,758 | 3% | 6,901 | 5% | 6,830 | 3.6% | 1.05 | 0.97 | 1.01 |
| Ovigerous *Daphnia l.* | 3,209 | 1% | 1,902 | 1% | 2,556 | 1.4% | 0.93 | 0.84 | 0.88 |
| *Daphnia* sp. | 2,055 | 1% | 374 | 0% | 1,214 | 0.6% | 1.01 | 0.92 | 0.97 |
| Ovigerous *Daphnia* sp. | 255 | 0% | 54 | 0% | 155 | 0.1% | | | |
| *Holopedium* | - | 0% | - | 0% | - | 0.0% | | | |
| Ovigerous *Holopedium* | 85 | 0% | - | 0% | 43 | 0.0% | 0.7 | 0.75 | 0.73 |
| *Daphnia m.* | - | 0% | - | 0% | - | 0.0% | 2.27 | | |
| Ovigerous *Daphnia m.* | - | 0% | | 0% | - | 0.0% | 3.03 | | |
| Copepod nauplii | 4,109 | 2% | 3,145 | 2% | 3,627 | 1.9% | | | |
| Total | 242,401 | | 133,310 | | 187,856 | | | | |

**Table 20.**–Salmon Bay Lake zooplankton seasonal mean weighted biomass density (mg/m$^2$) and percent of total biomass, by species, at stations A and B and mean of values for both stations.

| Species | Station A | Percent | Station B | Percent | Mean | Percent |
|---|---|---|---|---|---|---|
| *Epischura* | 80.0 | 19% | 45.0 | 20% | 62.5 | 19% |
| *Cyclops* | 247.0 | 59% | 134.0 | 59% | 190.5 | 59% |
| Ovig. *Cyclops* | 5.0 | 1% | 5.0 | 2% | 5 | 2% |
| *Bosmina* | 43.0 | 10% | 21.0 | 9% | 32 | 10% |
| Ovig. *Bosmina* | 4.0 | 1% | 2.0 | 1% | 3 | 1% |
| *Daphnia l.* | 15.0 | 4% | 12.0 | 5% | 13.5 | 4% |
| Ovig. *Daphnia l.* | 16.0 | 4% | 8.0 | 4% | 12 | 4% |
| *Daphnia* sp. | 8.0 | 2% | 1.0 | 0% | 4.5 | 1% |
| Ovig. *Daphnia* sp. | 1.0 | 0% | 0.2 | 0% | 0.60 | 0% |
| *Holopedium* | | 0% | | 0% | | 0% |
| Ovig. *Holopedium* | 0.4 | 0% | | 0% | 0.2 | 0% |
| *Daphnia m.* | | 0% | | 0% | | 0% |
| Copepod nauplii | | 0% | | 0% | | 0% |
| Total | 419.4 | | 228.2 | | 323.8 | |

### Luck Lake

Similar to Salmon Bay Lake, *Cyclops* (56%) and *Bosimina* (31%) were the dominant zooplankters in 2003 (Table 21; Appendix B8). However, because of the size of *Epischura* planktors, they surpassed the *Bosimina* biomass in this lake (Table 22; Appendix B9). *Daphnia* sp. were also present in low numbers (3.5 mg/m$^2$) in 2003 (Table 22).

# DISCUSSION

Our primary objective was to measure the escapement in these three systems. While we reported a 2003 escapement of 11,000 for Thoms Lake (CV = 12%), we were unable to estimate the escapement into Salmon Bay and Luck lakes in 2003 because high water conditions or because of the failure of statistical assumptions—the latter, a failure that we do not fully understand. The two 2003 candidate estimates of 19,000 and 24,000 for Luck Lake contain statistical biases to some extent. Even so, these measures are probably still useful approximate benchmarks for comparisons with historical escapement estimates or with reported subsistence harvests. In spite of the problems with the 2003 estimates, the 2001 and 2002 escapement estimates for Thoms, Salmon Bay, and Luck lakes provide snapshots of these systems that are generally consistent and informative.

The Thoms Lake sockeye escapement estimate approximately doubled each year of the study (3,000 fish in 2001, 5,900 fish in 2002 and 11,000 fish in 2003). The reported subsistence harvest of sockeye salmon in marine waters was insignificant compared to the escapement sizes in the three study years; 163 fish in 2001, 320 fish in 2002 and 200 fish in 2003 (ADF&G, unpublished data). When we have conducted on-grounds verification of subsistence harvest in other systems, we have found that the actual harvest was underreported on the subsistence permits. Even so, allowing for substantial underreporting, the current level of subsistence harvest cannot be appreciably affecting the escapement level into Thoms Lake. When the U.S. Bureau of Fisheries operated a weir on Eagle Creek on this system from 1928 to 1931, the escapement estimates ranged from 2,000 to 15,700 (Lewis and Cartwright 2004).

**Table 21.–**The 2003 mean weighted zooplankton densities and lengths by station and total lake estimates in Luck Lake.

| | Mean weighted densities (number/$m^2$) | | | | | | Zooplankton mean weighted length (mm) | | |
|---|---|---|---|---|---|---|---|---|---|
| **Zooplankton species** | **Sta. A Mean** | **Sta. A Percent** | **Sta. B Mean** | **Sta. B Percent** | **Lake Mean** | **Lake Percent** | **Sta. A Mean** | **Sta. B Mean** | **Lake Mean** |
| *Epischura* | 11,320 | 11% | 6,616 | 7% | 8,968 | 9% | 1.17 | 1.13 | 1.15 |
| *Cyclops* | 56,743 | 53% | 57,697 | 59% | 57,220 | 56% | 0.68 | 0.68 | 0.68 |
| Ovig. *Cyclops* | 944 | 1% | 594 | 1% | 769 | 1% | 0.89 | 0.87 | 0.88 |
| *Bosmina* | 34,638 | 32% | 29,105 | 30% | 31,872 | 31% | 0.38 | 0.34 | 0.36 |
| Ovig. *Bosmina* | 557 | 1% | 913 | 1% | 735 | 1% | 0.45 | 0.44 | 0.45 |
| *Daphnia l.* | 1,430 | 1% | 1,766 | 2% | 1,598 | 2% | 0.73 | 0.69 | 0.71 |
| Ovig. *Daphnia l.* | 526 | 0% | 347 | 0% | 437 | 0% | 0.99 | 1.01 | 1.00 |
| Copepod nauplii | 693 | 1% | 1,450 | 1% | 1,072 | 1% | | | |
| Total | 106,851 | | 98,489 | | 102,670 | | | | |

**Table 22.** –Luck Lake zooplankton seasonal mean weighted biomass density (mg/$m^2$) and percent of total biomass, by species, at stations A and B and mean of values for both stations.

| **Species** | **Station A** | **Percent** | **Station B** | **Percent** | **Mean** | **Percent** |
|---|---|---|---|---|---|---|
| *Epischura* | 79 | 35.0% | 43 | 24.7% | 61 | 30.5% |
| *Cyclops* | 91 | 40.3% | 91 | 52.3% | 91 | 45.5% |
| Ovig. *Cyclops* | 3 | 1.3% | 2 | 1.1% | 2.5 | 1.3% |
| *Bosmina* | 47 | 20.8% | 30 | 17.2% | 38.5 | 19.3% |
| Ovig. *Bosmina* | 1 | 0.4% | 2 | 1.1% | 1.5 | 0.8% |
| *Daphnia l.* | 3 | 1.3% | 4 | 2.3% | 3.5 | 1.8% |
| Ovig. *Daphnia l.* | 2 | 0.9% | 2 | 1.1% | 2 | 1.0% |
| Copepod nauplii | | 0.0% | | 0.0% | | 0.0% |
| Total | 226.0 | | 174.0 | | 200.0 | |

Taken together with our measurements, we see no reason to conclude that escapements at Thoms Lake were unusually low or high between 2001 and 2003.

The sockeye salmon escapement into Salmon Bay Lake also approximately doubled between 2001 (20,000 fish) and 2002 (43,000 fish), and again, no estimate was available for 2003. Similar to Thoms Lake, the substantial increase in sockeye escapement between 2001 and 2002 looks to be the result of a favorable freshwater and marine environments, resulting in two strong brood years. The strong showing of age-1.2 sockeye salmon returning to Salmon Bay Lake in 2001 (48% of the escapement) and 2002 (42% of the escapement) and their cohorts (age-1.3) in 2002 (53% of escapement) and 2003 (73% of escapement) is consistent with 1997 and 1998 brood years having had high survival rates. If these brood years were unusually strong, then the 2003 sockeye return pushed by the strength of the 1.3 component, was very likely was above average as well.

In Salmon Bay Lake the reported sockeye subsistence harvest increased through the study, from 900 fish in 2001, to 1,200 fish in 2002, and finally to 1,900 fish in 2003. The number of permits also increased from 52 to 82 permits over this time. Even allowing for the possibility of substantial under reporting, we think that the increase in the subsistence sockeye harvest in 2003 of this magnitude will have very little affect on future sockeye recruitment. The commercial fisheries in areas adjacent to the Salmon Bay Lake system, subdistrict 106-30 and 106-41, also increased in 2003 (124,000 fish) compared to 2002 (57,000 fish), but in both years this harvest was less than the harvest in 2001 (169,000 fish). We assume that these commercial harvests reflect a catch of a broad mix of stocks, but we have no stock-specific information.

The sockeye escapement at Luck Lake also approximately doubled between 2001 (8,000 fish) and 2002 (16,000 fish), the two years for which we have estimates. Luck Lake is currently not listed on the ADF&G Subsistence Permit. In the two years we have measurements, the escapement was clearly large enough to accommodate moderate subsistence harvests. However, we expect that catch rates will remain low for this system, because it appears to be difficult to fish with a net at the mouth of the river, or to dip net fish in the river close to the road crossing. To date, no sockeye harvest in the Luck Lake outlet stream (Eagle River) or at the mouth of the stream has been reported on an ADF&G subsistence permit. Although some of this lack of a reported harvest could be due to either confusion about the permits or non-reporting, we assume this lack of reporting is at least partially an indication of a very low subsistence harvest in this system, relative to the escapement magnitudes we measured.

We assume the lack of subsistence fishing pressure is at least partially due to the remoteness of these systems. Although sockeye salmon can be very vulnerable to fishing in the Thoms Lake terminal area in years of low rainfall, we saw no evidence of people attempting to take their subsistence harvest there in 2003, a low rainfall year during the month of July. Similarly, we assume that the low exploitation on the returning sockeye salmon to Salmon Bay Lake is at least partially due to the remoteness of this system. The marine terminal area of Luck Lake is difficult to fish for sockeye salmon. Although a public road crosses Eagle River, the outlet stream of Luck Lake, large boulders and a difficult shoreline to navigate, discourages most people from fishing in this stream. This lack of fishing pressure gives us more reason to speculate that, in the near future at least, subsistence harvests pose little or no risk to sustainability in these systems.

Because the mark-recapture studies were conducted only in defined areas within these lakes, our study does leave some doubt as to whether the escapement sizes were actually larger than we measured in these years, and that we simply did not measure spawning in all parts of the lakes. We found that very few fish in Thoms, Salmon Bay and Luck lakes spawned outside of these restricted and readily delimited areas. All spawning that we observed occurred in one main lake tributary in both Thoms and Luck lakes. The majority of spawning in Salmon Bay Lake occurred in a pair of tributaries located in close proximity to each other. We feel reasonably certain that our escapement measures did adequately approximate the actual escapement magnitude in the study years. Yet, the potential for undercount only reinforces our conclusion that the subsistence harvest levels were very low during the study years, and pose little risk to sustainability in the near future.

The three lakes that we studied generally tended towards the middle of the range of zooplankton biomass density, and Daphnia biomass density and size measurements in 13 small sockeye systems in Southeast Alaska (Table 23). In these three study lakes we did not see a direct response of the zooplankton biomass to the abundance of sockeye fry in lake. For example, in Luck Lake the estimated sockeye fry abundance in 2002 (254,000 fry) was over twice as high as the level in 2001 (105,000 fry) and 2003 (122,000 fry). Yet the zooplankton biomass ($mg/m^2$) was about 30% higher in 2002 (316 $mg/m^2$) compared to 2001 (234 $mg/m^2$) and 2003 (201 $mg/m^2$). Daphnia biomass was about the same in 2001 (17 $mg/m^2$) and 2002 (18 $mg/m^2$) compared to 2003 (6 $mg/m^2$) and size of Daphnia was slightly larger in 2001 and 2002 (Table 23). Zooplankton biomass in Luck Lake was about average compared to other lakes in Southeast Alaska (Table 23). Although three years of observation is far too few to confidently think we understand these systems, the lack of response between our measurements of sockeye fry and zooplankton biomass leads us to speculate that escapements into this system are well below the level that will produce maximum fry recruitment out of the lake.

In summary, these lakes appear to us to be lightly exploited by the subsistence fisheries, with relatively large sockeye populations. Although we have no information on the harvest rate on these stocks in the commercial fisheries, the subsistence fisheries do not seem to be having any appreciable effect on the dynamics of these populations. With only three years of study we find it hard to be definite about our conclusions, yet we see no reason to recommend continuing annual surveys of the kind we conducted from 2001 to 2003. In short, we concluded that these escapement sizes varied within reasonable limits to sustain subsistence fisheries in Southeast Alaska.

**Table 23. –**The weighted mean total zooplankton and *Daphnia* biomass estimates by lake and the average size of the *Daphnia* sp. by lake for 2001, 2002 and 2003.

| 2001 | | | | 2002 | | | | 2003 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Lake** | **Zooplankton biomass (mg per m$^2$)** | **Daphnia biomass (mg per m$^2$)** | **Daphnia avg. size (mm)** | **Lake** | **Zooplankton biomass (mg per m$^{2)}$** | **Daphnia biomass (mg per m$^2$)** | **Daphnia avg. size (mm)** | **Lake** | **Zooplankton biomass (mg per m$^2$)** | **Daphnia biomass (mg per m$^2$)** | **Daphnia avg. size (mm)** |
| Sitkoh | 651 | 93 | 0.73 | Hoktaheen | 651 | 20 | 0.91 | Kutlaku | 618 | 84 | 0.51 |
| Kanalku | 371 | 119 | 0.95 | Sitkoh | 579 | 201 | 0.79 | Tumakof | 500 | 0 | 0.66 |
| Salmon Bay | 364 | 85 | 0.94 | Klawock | 499 | 16 | 0.9 | Klawock | 431 | 37 | 0.97 |
| Hoktaheen | 328 | 32 | 0.87 | Tumakof | 496 | 2 | 0.65 | Kanalku | 371 | 78 | 0.75 |
| Kook | 299 | 37 | 0.87 | Kanalku | 420 | 137 | 0.75 | Salmon Bay | 351 | 32 | 0.93 |
| Luck | 234 | 17 | 0.86 | Luck | 316 | 18 | 0.77 | Klag | 316 | 7 | 0.68 |
| Klawock | 217 | 12 | 0.94 | Kook | 315 | 52 | 0.8 | Luck | 201 | 6 | 0.73 |
| Klag | 181 | 4 | 0.65 | Klag | 222 | 5 | 0.97 | Thoms | 163 | 7 | 0.55 |
| Kutlaku | 177 | 32 | 0.63 | Salmon Bay | 205 | 19 | 0.75 | Eek | 147 | 0 | na |
| Falls | 151 | 0 | 0.66 | Kutlaku | 131 | 35 | 0.51 | Hetta | 45 | 2 | 0.68 |
| Thoms | 144 | 9 | 0.6 | Thoms | 119 | 7 | 0.57 | Falls | 29 | 1 | 0.66 |
| Hetta | 34 | 0 | 0.63 | Hetta | 49 | 7 | 0.67 | Sitkoh | na | na | na |
| Gut | 33 | 1 | 0.6 | Falls | 41 | 1 | 0.69 | Kook | na | na | na |
| | | | | Gut | 24 | 1 | 0.61 | Gut | na | na | na |
| **Average** | **245** | **34** | **0.76** | **Average** | **311** | **40** | **0.75** | **Average** | **288** | **23** | **0.71** |
| **Median** | **217** | **17** | **0.73** | **Median** | **269** | **17** | **0.75** | **Median** | **316** | **7** | **0.68** |

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# APPENDIX A

**Appendix A1.–**The reported subsistence harvest by year for Thoms and Salmon Bay lakes, 1985–2003.

| | Thoms Lake | | | Salmon Bay Lake | | |
|---|---|---|---|---|---|---|
| Year | No. sockeye salmon | No. permits | Sockeye salmon per permit | No. sockeye salmon | No. permits | Sockeye salmon per permit |
| 1985 | 253 | 28 | 9 | 23 | 3 | 8 |
| 1986 | 287 | 30 | 10 | 95 | 11 | 9 |
| 1987 | 426 | 46 | 9 | 136 | 12 | 11 |
| 1988 | 103 | 10 | 10 | 83 | 8 | 10 |
| 1989 | 187 | 21 | 9 | 280 | 23 | 12 |
| 1990 | 146 | 16 | 9 | 627 | 36 | 17 |
| 1991 | 171 | 16 | 11 | 468 | 36 | 13 |
| 1992 | 380 | 30 | 13 | 704 | 64 | 11 |
| 1993 | 615 | 34 | 18 | 472 | 42 | 11 |
| 1994 | 356 | 31 | 11 | 464 | 38 | 12 |
| 1995 | 292 | 27 | 11 | 483 | 43 | 11 |
| 1996 | 203 | 15 | 14 | 619 | 57 | 11 |
| 1997 | 137 | 13 | 11 | 416 | 37 | 11 |
| 1998 | 346 | 33 | 10 | 724 | 67 | 11 |
| 1999 | 483 | 27 | 18 | 656 | 67 | 10 |
| 2000 | 477 | 40 | 12 | 625 | 62 | 10 |
| 2001 | 163 | 20 | 8 | 892 | 52 | 17 |
| 2002 | 320 | 17 | 19 | 1,160 | 61 | 19 |
| 2003 | 194 | 18 | 11 | 1,916 | 82 | 23 |

**Appendix A2.–**Field notes for mark-recapture studies performed at Thoms Lake, Luck Lake, and Salmon Bay Lake.

**THOMS LAKE**

The mark-recapture study design at Thoms Lake was constructed to use a pooled Petersen or stratified Darroch estimate in the analysis. This entailed marking fish at the mouth of the river (N 56º 14.16' W 132º 14.49) with seine nets and recovering marks by dip netting fish in the stream up to the barrier falls (N 56º 14.51' W 132º 14.01). The crew concentrated on marking fish the first few trips in the deep slough, shifting the effort to the recovery phase as the season progressed. I do not think this was the best study design for Thoms Creek. It was very difficult to seine in the deep slough just above the mouth due to the net hang-ups and the debris in the net. It sometimes took us 1–2 hours per set and we often only caught 25 or fewer sockeye salmon. The main stream starts around the corner from the deep slough. A better approach, in our opinion, would be to use the modified Jolly-Seber mark-recapture study design with dip nets in the stream above the slough for both the marking (day 1) and the recovery (day 2) in the same trip, making 4-5 trips per season (see Conitz and Cartwright 2005 for details). It is very easy to dip net fish in the majority of the stream above the slough unless the water is high.

The outlet stream of Thoms Lake is susceptible to beavers blocking the entire outlet stream as the water leaves the lake. It would be beneficial if the Forest Service or ADF&G checked this annually when flying over the area sometime at the beginning of July.

**LUCK LAKE**

The mark-recapture study design at Luck Lake was constructed to use a pooled Petersen or stratified Darroch estimate in the analysis. This seemed appropriate for this system. The east side of the mouth of the inlet stream was excellent for catching fish unless water was really high. We placed the boat and net up stream and did a wide circle with the net to herd the fish to the bank. The best place to do the recovery, especially in high water is the tributary (upper limit was N 55 54.88 W 132 45.63). The mainstem was walked to the bridge (N 55 54.88 W 132 45.63). Because this is a large river and escapement was high compared to other systems, it is best to have four or five people in good shape for the recovery phase (fish were captured with dip nets) The focus, however, should be getting as many marks out in the marking phase at the mouth because of the relatively easy place to capture them. Spending three days per trip on this system would allow the crew to walk the stream and set up camp on day one and then concentrate on the capture of fish on the other two days.

**SALMON BAY LAKE**

The mark-recapture study design at Salmon Bay Lake was also constructed to use a pooled Petersen or stratified Darroch estimate in the analysis. This seemed appropriate for this system. Fish were not observed spawning in any area other than the two inlet streams surveyed during the mark-recapture study. Although it is possible to survey both inlet streams in a 2-day trip, the SW inlet stream is a long walk to the falls. During high water, both inlet streams are difficult to fish during the marking phase at the mouth and during the recovery phase in the streams. The SW inlet steam has a large alluvial fan at its mouth. The fish concentrate at the edge of the drop off to deep water and are easy to seine in this area. If the water is low, the SW inlet stream has a good camping site by the mouth. Otherwise, it is best to commute by boat from the cabin at the other end of the lake.

**Appendix A3.–**The number of adult sockeye salmon sampled in Thoms Lake by age and year, 1982–2003. The total number and percent of sockeye salmon represented by each age class was calculated.

| Age | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | *n* | Percent of Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **0.2** | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.0% |
| **1.1** | 57 | 16 | 1 | 4 | 10 | 0 | 1 | 20 | 13 | 0 | 28 | 1 | 0 | 117 | 5 | 12 | 35 | 44 | 34 | 0 | 8 | 12 | 418 | 4.5% |
| **1.2** | 6 | 33 | 33 | 8 | 27 | 25 | 9 | 96 | 32 | 0 | 36 | 127 | 0 | 11 | 69 | 15 | 75 | 154 | 109 | 21 | 49 | 43 | 978 | 10.4% |
| **1.3** | 174 | 73 | 305 | 162 | 4 | 99 | 2 | 6 | 82 | 0 | 54 | 100 | 0 | 6 | 56 | 209 | 145 | 91 | 161 | 253 | 47 | 28 | 2,057 | 21.9% |
| **2.1** | 15 | 31 | 2 | 0 | 114 | 45 | 2 | 82 | 83 | 0 | 30 | 43 | 0 | 151 | 62 | 42 | 4 | 41 | 23 | 5 | 67 | 35 | 877 | 9.3% |
| **2.2** | 27 | 45 | 19 | 68 | 132 | 117 | 192 | 215 | 289 | 0 | 297 | 102 | 0 | 173 | 153 | 79 | 23 | 127 | 25 | 77 | 317 | 223 | 2,700 | 28.8% |
| **2.3** | 230 | 221 | 246 | 95 | 80 | 77 | 52 | 155 | 52 | 0 | 58 | 173 | 0 | 93 | 218 | 147 | 14 | 89 | 104 | 36 | 29 | 141 | 2,310 | 24.6% |
| **2.4** | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.0% |
| **3.1** | 0 | 0 | 0 | 0 | 5 | 5 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11 | 0.1% |
| **3.2** | 0 | 0 | 0 | 0 | 1 | 16 | 0 | 0 | 3 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 22 | 0.2% |
| **3.3** | 0 | 0 | 1 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0.1% |
| **4.1** | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.0% |
| **Total** | 510 | 419 | 607 | 337 | 375 | 387 | 259 | 574 | 554 | 0 | 504 | 548 | 0 | 553 | 564 | 504 | 296 | 546 | 456 | 392 | 517 | 482 | 9,384 | |

**Appendix A4.–**The number of adult sockeye salmon sampled in Salmon Bay Lake by age and year, 1982-2003. The total number and percent of sockeye salmon represented by each age class was calculated.

| Age | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | *n* | Percent of Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **0.2** | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.0% |
| **0.3** | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0.0% |
| **1.1** | 9 | 63 | 2 | 17 | 1 | 161 | 9 | 7 | 0 | 11 | 19 | 48 | 24 | 37 | 37 | 15 | 25 | 11 | 16 | 2 | 2 | 6 | 522 | 3.3% |
| **1.2** | 195 | 180 | 286 | 120 | 322 | 173 | 1721 | 31 | 0 | 254 | 35 | 207 | 20 | 184 | 32 | 257 | 55 | 86 | 57 | 244 | 218 | 74 | 4751 | 30.0% |
| **1.3** | 981 | 205 | 298 | 1055 | 762 | 1490 | 224 | 488 | 0 | 180 | 141 | 91 | 405 | 109 | 302 | 219 | 370 | 316 | 131 | 196 | 275 | 267 | 8505 | 53.6% |
| **1.4** | 1 | 0 | 0 | 1 | 9 | 3 | 6 | 0 | 0 | 1 | 1 | 4 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 28 | 0.2% |
| **2.1** | 1 | 3 | 0 | 4 | 1 | 27 | 8 | 1 | 0 | 22 | 0 | 47 | 12 | 23 | 17 | 6 | 11 | 13 | 1 | 1 | 0 | 0 | 198 | 1.2% |
| **2.2** | 68 | 36 | 1 | 37 | 70 | 78 | 64 | 30 | 0 | 19 | 22 | 48 | 45 | 45 | 27 | 30 | 23 | 32 | 30 | 6 | 19 | 6 | 736 | 4.6% |
| **2.3** | 43 | 40 | 5 | 108 | 91 | 139 | 47 | 10 | 0 | 30 | 14 | 101 | 25 | 104 | 28 | 27 | 44 | 26 | 42 | 50 | 8 | 13 | 995 | 6.3% |
| **2.4** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.0% |
| **3.1** | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 4 | 0 | 5 | 0 | 1 | 0 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 16 | 0.1% |
| **3.2** | 3 | 0 | 0 | 0 | 0 | 17 | 0 | 0 | 0 | 11 | 2 | 1 | 2 | 2 | 1 | 3 | 17 | 0 | 0 | 0 | 0 | 0 | 59 | 0.4% |
| **3.3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 4 | 14 | 1 | 1 | 0 | 0 | 11 | 0 | 2 | 6 | 0 | 0 | 40 | 0.3% |
| **Total** | 1301 | 527 | 592 | 1342 | 1257 | 2092 | 2079 | 567 | 0 | 533 | 238 | 566 | 534 | 507 | 445 | 558 | 560 | 484 | 279 | 505 | 522 | 366 | 15854 | |

**Appendix A5.–**The number of adult sockeye salmon sampled in Luck Lake by age and year, 1982-2003. The total number and percent of sockeye salmon represented by each age class was calculated.

| **Age** | **1982** | **1983** | **1984** | **1985** | **1986** | **1987** | **1988** | **1989** | **1990** | **1991** | **1992** | **1993** | **1994** | **1995** | **1996** | **1997** | **1998** | **1999** | **2000** | **2001** | **2002** | **2003** | ***n*** | **Percent of Total** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1.1** | 142 | 45 | 46 | 64 | 20 | 40 | 0 | 0 | 61 | 58 | 150 | 17 | 134 | 186 | 47 | 137 | 30 | 86 | 58 | 57 | 15 | 53 | 1,446 | 16.4% |
| **1.2** | 39 | 237 | 32 | 111 | 56 | 11 | 36 | 0 | 323 | 142 | 92 | 174 | 23 | 177 | 211 | 146 | 158 | 69 | 268 | 95 | 337 | 111 | 2,848 | 32.3% |
| **1.3** | 133 | 84 | 207 | 26 | 72 | 14 | 10 | 0 | 12 | 95 | 96 | 105 | 186 | 32 | 181 | 152 | 130 | 173 | 52 | 357 | 103 | 247 | 2,467 | 27.9% |
| **1.4** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0.0% |
| **2.1** | 1 | 36 | 12 | 36 | 17 | 1 | 0 | 0 | 38 | 76 | 107 | 63 | 20 | 29 | 61 | 77 | 73 | 11 | 15 | 5 | 19 | 35 | 732 | 8.3% |
| **2.2** | 25 | 6 | 29 | 16 | 40 | 3 | 10 | 0 | 80 | 32 | 42 | 60 | 22 | 22 | 51 | 20 | 113 | 52 | 19 | 26 | 44 | 64 | 776 | 8.8% |
| **2.3** | 27 | 36 | 9 | 12 | 17 | 1 | 0 | 0 | 31 | 23 | 45 | 85 | 38 | 22 | 11 | 22 | 35 | 30 | 35 | 15 | 18 | 41 | 553 | 6.3% |
| **3.1** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0.0% |
| **3.2** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0.0% |
| **3.3** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.0% |
| Total | 367 | 444 | 335 | 265 | 222 | 70 | 56 | 0 | 550 | 426 | 532 | 504 | 423 | 468 | 562 | 554 | 540 | 421 | 448 | 555 | 536 | 551 | 8,829 | |

# APPENDIX B

**Appendix B1.–**The 2003 Thoms Lake temperature (º C) profiles by sample date and depth (m). The shaded temperature values represent the upper and lower thermocline depth for each sample period.

| Depth (m) | 8-May-03 | 6-Jun-03 | 1-Jul-03 | 26-Aug-03 | 7-Oct-02 |
|---|---|---|---|---|---|
| 1.0 | 12.1 | 16.7 | 15.6 | 17.5 | 11.8 |
| 2.0 | 12.1 | 14.2 | 15.5 | 17.4 | 11.8 |
| 3.0 | 12 | 12.8 | 15.5 | 17.3 | 11.5 |
| 4.0 | 10 | 11.6 | 13.6 | 15.2 | 11.4 |
| 5.0 | 7.3 | 9.7 | 11.3 | 14.4 | 11.1 |
| 6.0 | 6.2 | 8.6 | 8.7 | 11.5 | 10.7 |
| 7.0 | 5.7 | 7.3 | 7.6 | 9.5 | 10.5 |
| 8.0 | 5.4 | 6.4 | 6.7 | 7.8 | 10.0 |
| 9.0 | 5.3 | 6.1 | 6.3 | 6.8 | 8.2 |
| 10.0 | 4.9 | 6.0 | 6.1 | 6.4 | 7.1 |
| 11.0 | | 5.9 | 5.8 | | 6.5 |
| 12.0 | | 5.6 | 5.7 | 6.0 | 6.3 |
| 13.0 | | 5.5 | 5.6 | | |
| 14.0 | | 5.4 | 5.6 | 5.8 | |
| 15.0 | 5.1 | 5.4 | 5.5 | | 6.0 |
| 16.0 | | | | | |
| 17.0 | | | | | |
| 18.0 | | | | 5.6 | |
| 19.0 | | | | | |
| 20.0 | 4.9 | 5.2 | 5.3 | 5.5 | 5.7 |
| 25.0 | 4.8 | 5.1 | 5.2 | | 5.7 |
| 30.0 | 4.4 | | | | |

**Appendix B2.–**The 2003 Salmon Bay Lake temperature (º C) profiles by sample date and depth (m). The shaded temperature values represent the upper and lower thermocline depth for each sample period.

| Depth (m) | 8-May-03 | 6-Jun-06 | 1-Jul-03 | 23-Aug-03 | 10-Oct-03 |
|---|---|---|---|---|---|
| 1 | 11.5 | 14.4 | 15 | 16.8 | 10.6 |
| 2 | 11.4 | 13.7 | 14.4 | 16.4 | 10.5 |
| 3 | 10.8 | 12 | 14.3 | 16.3 | 10.5 |
| 4 | 10.4 | 11.1 | 14 | 16.3 | 10.5 |
| 5 | 8.5 | 10.2 | 12.9 | 16.2 | 10.5 |
| 6 | 7.5 | 9.7 | 12 | 15.3 | 10.4 |
| 7 | 7.2 | 9.1 | 10.7 | 13.4 | 10.3 |
| 8 | 6.8 | 8.3 | 9.7 | 10.8 | 10 |
| 9 | 6.6 | 7.9 | 8.6 | 9.3 | 9.9 |
| 10 | 6.4 | 7.2 | 7.6 | 8.5 | 9.9 |
| 11 | | 7 | 7.4 | 8 | |
| 12 | | 6.7 | 7 | 7.5 | 9.5 |
| 13 | | 6.5 | 6.6 | | |
| 14 | | 6.3 | 6.4 | 7 | 9.1 |
| 15 | 5.7 | 6.2 | 6.2 | | |
| 16 | | | 6.1 | 6.5 | 8.1 |
| 17 | | | | | |
| 18 | | | 5.9 | 6.3 | 7.6 |
| 19 | | | | | |
| 20 | 5.3 | 5.4 | 5.6 | 6.1 | 7 |
| 25 | 5.1 | 4.9 | 5.1 | 5.5 | 6 |
| 30 | 4.6 | 4.7 | 4.8 | 5.1 | 5.3 |
| 35 | 4.4 | 4.6 | 4.6 | 4.7 | 4.9 |
| 40 | 4.2 | 4.4 | 4.4 | 4.5 | 4.6 |
| 45 | | 4.3 | | | 4.5 |

**Appendix B3.–**The 2003 Luck Lake temperature (º C) profiles by sample date and depth (m). The shaded temperature values represent the upper and lower thermocline depth for each sample period.

| Depth (m) | 8-May-03 | 6-Jun-03 | 1-Jul-03 | 22-Aug-03 | 10-Oct-03 |
|---|---|---|---|---|---|
| 1 | 10.2 | 13.2 | 14.1 | 16.4 | 10.3 |
| 2 | 10.1 | 12.6 | 14.1 | 16.4 | 10.2 |
| 3 | 9.7 | 11.1 | 13.7 | 16.4 | 10.2 |
| 4 | 9.3 | 10.4 | 13.4 | 16.4 | 10.2 |
| 5 | 9 | 9.6 | 12 | 16.3 | 10.2 |
| 6 | 8.3 | 9.4 | 11.5 | 14.3 | 10.1 |
| 7 | | 9.1 | 10.9 | 12 | 10.1 |
| 8 | | 8.8 | 10.5 | 10.7 | 10 |
| 9 | | 8.5 | 9.4 | 10 | 9.9 |
| 10 | 7.2 | 8.3 | 9.1 | 9.5 | 9.9 |
| 11 | | 7.5 | 8.4 | 8.8 | |
| 12 | | 7.3 | 8 | 8 | 9.6 |
| 13 | | 7 | 7.5 | | |
| 14 | | 6.9 | 7.1 | 7.1 | 9.1 |
| 15 | 6 | 6.6 | 6.8 | | |
| 16 | | | 6.5 | 6.6 | 7.7 |
| 17 | | | | | |
| 18 | | | 6.1 | 6.2 | 6.9 |
| 19 | | | | | |
| 20 | 5.1 | 5.8 | 5.9 | 6 | 6.6 |
| 25 | 4.9 | 5.2 | 5.3 | 5.5 | 5.9 |
| 30 | | 5 | | 5.3 | 5.7 |

**Appendix B4.–**The 2003 zooplankton densities (no./m$^2$) by species, sample date and station in Thoms Lake.

| Station | Zooplankton species | 8-May | 5-Jun | 1-Jul | 26-Aug | 7-Oct | Seasonal Mean |
|---|---|---|---|---|---|---|---|
| A | *Ergasilus* | | | | | | - |
| A | *Epischura* | | | | | | - |
| A | *Diaptomus* | 40,856 | 19,358 | 8,558 | 1,698 | 204 | 14,135 |
| A | Ovigerous *Diaptomus* | - | - | 102 | 679 | 102 | 177 |
| A | *Cyclops* | | 1,426 | 102 | 340 | 102 | 394 |
| A | Ovigerous *Cyclops* | | | | | | - |
| A | *Bosmina* | 4,483 | 24,147 | 46,867 | 52,641 | 23,332 | 30,294 |
| A | Ovigerous *Bosmina* | | | 102 | 1,868 | 2,445 | 883 |
| A | *Daphnia l.* | 2,140 | 3,974 | 3,057 | 3,566 | 2,700 | 3,087 |
| A | Ovigerous *Daphnia l.* | 713 | 509 | 611 | 679 | 509 | 604 |
| A | *Diaphanosoma* | | 102 | 1,732 | 79,300 | 509 | 16,329 |
| A | Ovigerous *Diaphanosoma* | | | | 1,189 | - | 238 |
| A | *Holopedium* | 611 | 4,177 | 6,011 | 4,245 | 51 | 3,019 |
| A | Ovigerous *Holopedium* | 204 | 306 | 815 | 170 | | 299 |
| A | *Polyphemus* | | 408 | 611 | 1,189 | | 442 |
| A | *Chaoborus* | 285 | 234 | 51 | | 132 | 140 |
| A | Copepod nauplii | 10,800 | | | | | 2,160 |
| **A** | **Total** | | | | | | **72,200** |
| B | *Ergasilus* | | | | | | - |
| B | *Epischura* | | | | | | - |
| B | *Diaptomus* | 20,105 | 15,588 | 5,094 | 9,170 | 883 | 10,168 |
| B | Ovigerous *Diaptomus* | | | 85 | 1,019 | 883 | 397 |
| B | *Cyclops* | 815 | 713 | 679 | 2,717 | 611 | 1,107 |
| B | Ovigerous *Cyclops* | | | | | | - |
| B | *Bosmina* | 2,921 | 22,415 | 47,207 | 26,830 | 15,690 | 23,013 |
| B | Ovigerous *Bosmina* | | | | | 3,464 | 693 |
| B | *Daphnia l.* | 1,494 | 3,668 | 4,924 | 4,075 | 5,094 | 3,851 |
| B | Ovigerous *Daphnia l.* | 272 | 1,223 | 1,104 | - | 1,970 | 914 |
| B | *Diaphanosoma* | | 509 | 1,019 | 81,508 | 815 | 16,770 |
| B | Ovigerous *Diaphanosoma* | | | | - | | - |
| B | *Holopedium* | 1,426 | 5,400 | 3,566 | 3,396 | - | 2,758 |
| B | Ovigerous *Holopedium* | 136 | 1,019 | 340 | 1,019 | | 503 |
| B | *Polyphemus* | | 713 | 509 | 1,698 | | 584 |
| B | *Chaoborus* | 66 | 122 | 92 | | 443 | 145 |
| B | Copepod nauplii | 10,800 | | | | 408 | 2,242 |
| **B** | **Total** | | | | | | **63,143** |

**Appendix B5.–**Body length (mm) and weight (mg/m$^2$) of zooplankton in Thoms Lake in 2003 by species, sample date and seasonal mean. For the biomass estimate, a regression of wet length on dry weigh is used to convert lengths to weight for each species (Koenings et al. 1987).

| | | | | | | | Seasonal mean | |
|---|---|---|---|---|---|---|---|---|
| **Station** | **Zooplankton Species** | **8-May** | **5-Jun** | **1-Jul** | **26-Aug** | **7-Oct** | **Weighted length (mm)** | **Weighted biomass (mg/m2)** |
| A | *Ergasilus* | | | | | | | |
| A | *Epischura* | | | | | | | |
| A | *Diaptomus* | 1.04 | 1.29 | 1.5 | 1.77 | 1.6 | 1.18 | 97.71 |
| A | Ovigerous *Diaptomus* | 2.35 | 2.28 | 2.1 | 1.87 | 1.91 | 1.90 | 4.65 |
| A | *Cyclops* | | 0.61 | 0.62 | 0.61 | 0.62 | 0.61 | 0.49 |
| A | Ovigerous *Cyclops* | | | | | | | |
| A | *Bosmina* | 0.32 | 0.31 | 0.31 | 0.33 | 0.37 | 0.33 | 29.12 |
| A | Ovigerous *Bosmina* | | | | 0.37 | 0.4 | 0.39 | 1.22 |
| A | *Daphnia l.* | 0.58 | 0.52 | 0.52 | 0.59 | 0.53 | 0.55 | 3.82 |
| A | Ovigerous *Daphnia l.* | 0.82 | 0.71 | 0.75 | 0.72 | 0.76 | 0.75 | 1.51 |
| A | *Diaphanosoma* | | 0.48 | 0.46 | 0.49 | 0.46 | 0.49 | 15.92 |
| A | Ovigerous *Diaphanosoma* | | | | 0.62 | 0.72 | 0.62 | 0.39 |
| A | *Holopedium* | 0.48 | 0.48 | 0.49 | 0.53 | 0.5 | 0.50 | 6.28 |
| A | Ovigerous *Holopedium* | 0.51 | 0.54 | 0.52 | 0.69 | | 0.54 | 0.76 |
| A | *Polyphemus* | | 0.48 | 0.45 | 0.5 | | 0.48 | 0.13 |
| A | *Chaoborus* | | | | | | | |
| A | Copepod nauplii | | | | | | | |
| **A** | **Total** | | | | | | | **162.00** |
| B | *Ergasilus* | | | | | | | |
| B | *Epischura* | | | | | | | |
| B | *Diaptomus* | 1.02 | 1.4 | 1.5 | 1.78 | 1.41 | 1.33 | 97.40 |
| B | Ovigerous *Diaptomus* | | | 2.19 | 1.89 | 1.83 | 1.88 | 10.08 |
| B | *Cyclops* | 0.53 | 0.6 | 0.65 | 0.57 | 0.6 | 0.58 | 1.25 |
| B | Ovigerous *Cyclops* | | | | | | | |
| B | *Bosmina* | 0.33 | 0.32 | 0.31 | 0.34 | 0.37 | 0.33 | 22.29 |
| B | Ovigerous *Bosmina* | | | | | 0.4 | 0.40 | 1.02 |
| B | *Daphnia l.* | 0.59 | 0.53 | 0.49 | 0.63 | 0.5 | 0.54 | 4.61 |
| B | Ovigerous *Daphnia l.* | 0.79 | 0.77 | 0.74 | 0.77 | 0.79 | 0.77 | 2.40 |
| B | *Diaphanosoma* | | 0.54 | 0.4 | 0.52 | 0.46 | 0.52 | 18.52 |
| B | Ovigerous *Diaphanosoma* | | | | 0.67 | | 0.67 | 0.00 |
| B | *Holopedium* | 0.49 | 0.49 | 0.46 | 0.49 | 0.53 | 0.48 | 5.30 |
| B | Ovigerous *Holopedium* | 0.55 | 0.56 | 0.52 | 0.65 | | 0.59 | 1.59 |
| B | *Polyphemus* | | 0.55 | 0.5 | 0.5 | | 0.51 | 0.19 |
| B | *Chaoborus* | | | | | | | |
| B | Copepod nauplii | | | | | | | |
| **B** | **Total** | | | | | | | **164.64** |

**Appendix B6.–**The 2003 zooplankton densities (no./$m^2$) by species, sample date and station in Salmon Bay Lake.

| Station | Zooplankton species | 8-May | 5-Jun | 1-Jul | 23-Aug | 10-Oct | Seasonal mean |
|---|---|---|---|---|---|---|---|
| A | *Ergasilus* | | | | | | 0 |
| A | *Epischura* | 170 | 3,396 | 1,698 | 40,754 | 20,377 | 13,279 |
| A | *Diaptomus* | | | | | | - |
| A | *Cyclops* | 75,734 | 119,205 | 188,062 | 229,241 | 209,713 | 164,391 |
| A | Ovigerous *Cyclops* | 340 | 7,811 | 425 | | | 1,715 |
| A | *Bosmina* | 2,208 | 32,603 | 74,291 | 75,734 | 36,509 | 44,269 |
| A | Ovigerous *Bosmina* | - | 3,396 | 1,274 | 3,736 | 2,972 | 2,276 |
| A | *Daphnia l.* | 7,981 | 14,264 | 8,490 | 1,358 | 1,698 | 6,758 |
| A | Ovigerous *Daphnia l.* | 2,717 | 7,811 | 4,670 | - | 849 | 3,209 |
| A | *Daphnia* sp. | | 679 | 1,274 | 2,377 | 5,943 | 2,055 |
| A | Ovigerous *Daphnia* sp. | | - | - | - | 1,274 | 255 |
| A | *Holopedium* | | | | | | - |
| A | Ovigerous *Holopedium* | | | 425 | | | 85 |
| A | *Daphnia m.* | | - | - | - | - | - |
| A | Ovigerous *Daphnia m.* | | | - | | | - |
| A | Copepod nauplii | 20,547 | | | | | 4,109 |
| **A** | **Total** | **109,697** | **189,165** | **280,609** | **353,200** | **279,335** | **242,401** |
| B | *Ergasilus* | | | | | | |
| B | *Epischura* | | 2,802 | 3,770 | 9,509 | 18,611 | 6,938 |
| B | *Diaptomus* | | | | | | - |
| B | *Cyclops* | | | | | | 92,940 |
| B | Ovigerous *Cyclops* | | | | | | 1,797 |
| B | *Bosmina* | 201,053 | 79,980 | 33,826 | 82,731 | 67,108 | 17,850 |
| B | Ovigerous *Bosmina* | 679 | 7,387 | 917 | | | 1,410 |
| B | *Daphnia l.* | 7,472 | 21,905 | 18,849 | 14,943 | 26,083 | 6,901 |
| B | Ovigerous *Daphnia l.* | 340 | 3,821 | 306 | 1,494 | 1,087 | 1,902 |
| B | *Daphnia* sp. | 13,924 | 14,264 | 5,502 | 543 | 272 | 374 |
| B | Ovigerous *Daphnia* sp. | 3,057 | 4,075 | 2,241 | 136 | - | 54 |
| B | *Holopedium* | | | 509 | 272 | 1,087 | - |
| B | Ovigerous *Holopedium* | | | - | 272 | - | - |
| B | *Daphnia m.* | | | | | | - |
| B | Ovigerous *Daphnia m.* | | | - | | | 3,145 |
| B | Copepod nauplii | | | | | | |
| **B** | **Total** | **12,566** | | **3,158** | | | **133,310** |

**Appendix B7.–**Body length (mm) and weight (mg/m$^2$) of zooplankton in Salmon Bay Lake in 2003 by species, sample date and seasonal mean. For the biomass estimate, a regression of wet length on dry weigh is used to convert lengths to weight for each species (Koenings et al. 1987).

| | | | | | | | **Seasonal mean** | |
|---|---|---|---|---|---|---|---|---|
| **Station** | **Zooplankton species** | **8-May** | **5-Jun** | **1-Jul** | **23-Aug** | **10-Oct** | **Weighted length (mm)** | **Weighted biomass (mg/m2)** |
| A | *Ergasilus* | | | | | | | |
| A | *Epischura* | 0.6 | 1.1 | 1.65 | 1.01 | 1.27 | 1.1 | 80.3 |
| A | *Diaptomus* | | | | | | | |
| A | *Cyclops* | 0.61 | 0.62 | 0.69 | 0.67 | 0.68 | 0.7 | 246.7 |
| A | Ovigerous *Cyclops* | 0.93 | 0.87 | 0.95 | | | 0.9 | 4.7 |
| A | *Bosmina* | 0.4 | 0.31 | 0.33 | 0.32 | 0.35 | 0.3 | 42.9 |
| A | Ovigerous *Bosmina* | 0.46 | 0.45 | 0.42 | 0.38 | 0.39 | 0.4 | 3.5 |
| A | *Daphnia l.* | 0.68 | 0.6 | 0.88 | 1.1 | 0.86 | 0.7 | 15.4 |
| A | Ovigerous *Daphnia l.* | 0.94 | 1 | 1.17 | 1.22 | 1.16 | 1.0 | 16.3 |
| A | *Daphnia* sp. | | 0.6 | 1.53 | 0.76 | 0.9 | 0.9 | 8.0 |
| A | Ovigerous *Daphnia* sp. | | 1.06 | 1.26 | 0.93 | 1.01 | 1.0 | 1.2 |
| A | *Holopedium* | | | | | | | |
| A | Ovigerous *Holopedium* | | | 0.7 | | | 0.7 | 0.4 |
| A | *Daphnia m.* | | 2.26 | 2.43 | 2.23 | 2.15 | 2.3 | - |
| A | Ovigerous *Daphnia m.* | | | 3.03 | | | 3.0 | - |
| A | Copepod nauplii | | | | | | | |
| **A** | **Total** | | | | | | | **419.3** |
| B | *Ergasilus* | | | | | | | |
| B | *Epischura* | | 1.06 | 1.31 | 0.85 | 1.26 | 1.14 | 44.95 |
| B | *Diaptomus* | | | | | | | |
| B | *Cyclops* | 0.71 | 0.65 | 0.63 | 0.56 | 0.61 | 0.65 | 134.28 |
| B | Ovigerous *Cyclops* | 0.93 | 0.86 | 0.9 | | | 0.87 | 4.79 |
| B | *Bosmina* | 0.44 | 0.34 | 0.39 | 0.32 | 0.36 | 0.36 | 21.27 |
| B | Ovigerous *Bosmina* | 0.45 | 0.46 | 0.4 | 0.37 | 0.39 | 0.43 | 2.39 |
| B | *Daphnia l.* | 0.56 | 0.65 | 0.74 | 1.07 | 0.8 | 0.64 | 11.88 |
| B | Ovigerous *Daphnia l.* | 0.83 | 1.01 | 1.09 | 1.24 | 1.12 | 0.97 | 8.27 |
| B | *Daphnia* sp. | | | 0.73 | 0.79 | 0.9 | 0.84 | 1.17 |
| B | Ovigerous *Daphnia* sp. | | | 1.2 | 0.92 | 1.05 | 0.92 | 0.21 |
| B | *Holopedium* | | | | | | | |
| B | Ovigerous *Holopedium* | | | 0.75 | | | 0.75 | 0.00 |
| B | *Daphnia m.* | | | | | | | |
| B | Ovigerous *Daphnia m.* | | | | | | | |
| B | Copepod nauplii | | | | | | | |
| **B** | **Total** | | | | | | | **229.20** |

**Appendix B8.–**The 2003 zooplankton densities (no./m$^2$) by species, sample date and station in Luck Lake.

| Station | Zooplankton species | 8-May | 5-Jun | 1-Jul | 22-Aug | 10-Oct | Seasonal mean |
|---|---|---|---|---|---|---|---|
| A | *Ergasilus* | | | | | | - |
| A | *Epischura* | 1,019 | 5,706 | 8,015 | 22,500 | 19,358 | 11,320 |
| A | *Diaptomus* | | | | | | - |
| A | *Cyclops* | 38,411 | 19,969 | 49,584 | 90,423 | 85,329 | 56,743 |
| A | Ovigerous *Cyclops* | 1,936 | 2,649 | 136 | | | 944 |
| A | *Bosmina* | 6,623 | 23,128 | 48,090 | 95,093 | 255 | 34,638 |
| A | Ovigerous *Bosmina* | 102 | 204 | 1,630 | 849 | | 557 |
| A | *Daphnia l.* | 815 | 1,936 | 2,445 | 1,698 | 255 | 1,430 |
| A | Ovigerous *Daphnia l.* | 102 | 917 | 679 | 425 | 509 | 526 |
| A | *Daphnia g.* | | | | | | - |
| A | *Holopedium* | | | | | | - |
| A | *Chydorinae* | | | | | | - |
| A | Copepod nauplii | 2,547 | 917 | | | | 693 |
| **A** | **Total** | | | | | | **106,851** |
| B | *Ergasilus* | | | | | | - |
| B | *Epischura* | 340 | 10,596 | 7,064 | 7,472 | 7,607 | 6,616 |
| B | *Diaptomus* | | | | | | - |
| B | *Cyclops* | 23,585 | 17,117 | 37,222 | 123,620 | 86,942 | 57,697 |
| B | Ovigerous *Cyclops* | 255 | 1,766 | 951 | | | 594 |
| B | *Bosmina* | 5,773 | 22,415 | 62,829 | 54,508 | - | 29,105 |
| B | Ovigerous *Bosmina* | 85 | 679 | 2,445 | 1,358 | | 913 |
| B | *Daphnia l.* | 1,528 | 1,766 | 2,241 | 2,208 | 1,087 | 1,766 |
| B | Ovigerous *Daphnia l.* | 340 | 272 | 272 | 849 | - | 347 |
| B | *Daphnia g.* | | | | | | - |
| B | *Holopedium* | | | | | | - |
| B | *Chydorinae* | | | | | | - |
| B | Copepod nauplii | 4,330 | 1,223 | 1,698 | | | 1,450 |
| **B** | **Total** | | | | | | **98,489** |

**Appendix B9.–**Body length (mm) and weight (mg/m$^2$) of zooplankton in Luck Lake in 2003 by species, sample date and seasonal mean. For the biomass estimate, a regression of wet length on dry weigh is used to convert lengths to weight for each species (Koenings et al. 1987).

| | | | | | | | Seasonal mean | |
|---|---|---|---|---|---|---|---|---|
| **Station** | **Zooplankton species** | **8-May** | **5-Jun** | **1-Jul** | **22-Aug** | **10-Oct** | **Weighted length** | **Weighted biomass** |
| A | *Ergasilus* | | | | | | | |
| A | *Epischura* | 0.64 | 0.83 | 1.46 | 1.07 | 1.29 | 1.17 | 79.28 |
| A | *Diaptomus* | | | | | | | |
| A | *Cyclops* | 0.81 | 0.82 | 0.55 | 0.66 | 0.70 | 0.68 | 90.73 |
| A | Ovigerous *Cyclops* | 0.87 | 0.90 | 0.88 | | | 0.89 | 2.63 |
| A | *Bosmina* | 0.35 | 0.33 | 0.34 | 0.42 | 0.54 | 0.38 | 46.70 |
| A | Ovigerous *Bosmina* | 0.46 | 0.41 | 0.41 | 0.53 | | 0.45 | 1.05 |
| A | *Daphnia l.* | 0.64 | 0.60 | 0.81 | 0.81 | 0.81 | 0.73 | 3.36 |
| A | Ovigerous *Daphnia l.* | 0.90 | 0.91 | 0.92 | 1.14 | 1.10 | 0.99 | 2.35 |
| A | *Daphnia g.* | | | | | | | |
| A | *Holopedium* | | | | | | | |
| A | *Chydorinae* | | | | | | | |
| A | Copepod nauplii | | | | | | | |
| **A** | **Total** | | | | | | | **226.09** |
| B | *Ergasilus* | | | | | | | |
| B | *Epischura* | 0.64 | 0.91 | 1.18 | 1.16 | 1.4 | 1.1340367 | 42.55355744 |
| B | *Diaptomus* | | | | | | | |
| B | *Cyclops* | 0.82 | 0.8 | 0.56 | 0.65 | 0.71 | 0.68 | 90.79 |
| B | Ovigerous *Cyclops* | 0.87 | 0.87 | 0.87 | | | 0.87 | 1.59 |
| B | *Bosmina* | 0.36 | 0.4 | 0.3 | 0.35 | 0.45 | 0.34 | 29.82 |
| B | Ovigerous *Bosmina* | 0.5 | 0.48 | 0.39 | 0.52 | | 0.44 | 1.68 |
| B | *Daphnia l.* | 0.61 | 0.58 | 0.77 | 0.76 | 0.7 | 0.69 | 3.67 |
| B | Ovigerous *Daphnia l.* | 0.89 | 0.87 | 0.91 | 1.13 | 1.16 | 1.01 | 1.62 |
| B | *Daphnia g.* | | | | | | | |
| B | *Holopedium* | | | | | | | |
| B | *Chydorinae* | | | | | | | |
| B | Copepod nauplii | | | | | | | |
| **B** | **Total** | | | | | | | **171.72** |